NAVIS

North Atlantic Vessel Identification System

BEXUS Flight 2009

Student Experiment Documentation

Aalborg University

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Preface

The SED (Student Experiment Documentation) provides EuroLaunch and other readers with all important information about the NAVIS (North Atlantic Vessel Identification System) experiment from Aalborg University. During all experiment phases - development, experiment production, launch campaign and post flight - this SED is the place to find documentation that describes the experiment in detail. The SED is built on the basis of "Guidelines for Student Experiment Documentation", except from section 3.7, Economy. In this version 2 of the SED, nearly all chapters are altered, and more information has been put to this document, as well as the budgets has been adjusted. A special focus has been on the mechanical system, which was poorly documented in the first version of this SED. Also note that AIS2 subsystem has changed its computing platform to an Analog Devices DSP.

The NAVIS experiment was formerly known as "AAUSAT3 AIS receiver".

The goal of the NAVIS experiment is to test two student developed AIS receivers, as a milestone in the development of the 3rd Cubesat from Aalborg University.

The NAVIS team can be contacted at `aausat3bexus@space.aau.dk`. Our website is located at `http://navis-project.eu`.

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Chapter 1

Introduction

1.1 Experiment Objectives

The Danish Maritime Safety Administration's (DaMSA) mission is to have the safest seaways in the world. They are well underway in the Danish waters, but around Greenland, which is also DaMSA's area of responsibility, the waters are not perfectly charted. To build a tracking system around Greenland will be an enourmase task due to the size of Greenland and the hostile environment. Therefore DaMSA would like to track the ship traffic by Automatic Identification System (AIS) as they are doing in Denmark, so that they know where to concentrate their charting activities. A short introduction to AIS for readers who are unfamiliar with the system is found in Appendix B.

DaMSA traditionally tracks ships via AIS by placing ground stations on the shores, to receive transmissions from the ships, but also to act as electronic lighthouses. This method is impractical in the regions around Greenland and will still not cover the open seas, as the ground stations can not receive transmissions from ships beyond the line of sight. Ground stations typically receives signal from approximately 40 nautical miles away (74 km.)[Cervera 08].

AAUSAT3 is the third student satellite developed at Aalborg University. The satellite's mission is to evaluate the possibilities of receiving AIS messages from ships via satellite as a preliminary step in the development of operational AIS satellites. By analyzing the communication path from ship to satellite, it has been estimated that it is possible to receive AIS signals in both 35 km altitude (Appendix I) and in Low-Earth Orbit (LEO).

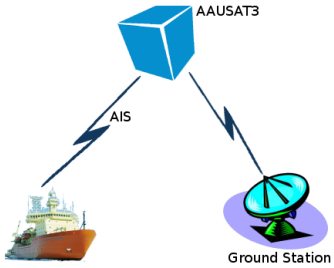

Figure 1.1: AAUSAT3 communication path

The main objective of the NAVIS project is to test the ability of two student developed AIS receivers to receive and decode real life AIS radio signals in high altitude. As the receivers are designed for AAUSAT3 a number of natural restrictions applies such as size, weight, power consumption and general robustness of the construction. Based on the outcome of the BEXUS flight, the final design of the primary payload of AAUSAT3 will be selected. The balloon flight

will include an adapted Engineering Model (EM) of AAUSAT3, to test the satellite design.

1.2 Experiment Overview

The AIS system was originally only intended to be used for ship-to-ship and ship-to-land transmission. This design raises some challenges when receiving signals in space. A satellite will be able to receive AIS messages from a much larger area than a ground station, due to the increased altitude and thereby line-of-sight. This means that a satellite might receive collided AIS massages, due to the fact that a ship only synchronizes its transmissions with other ships within the line-of-sight. This problem is illustrated in Figure 1.2.

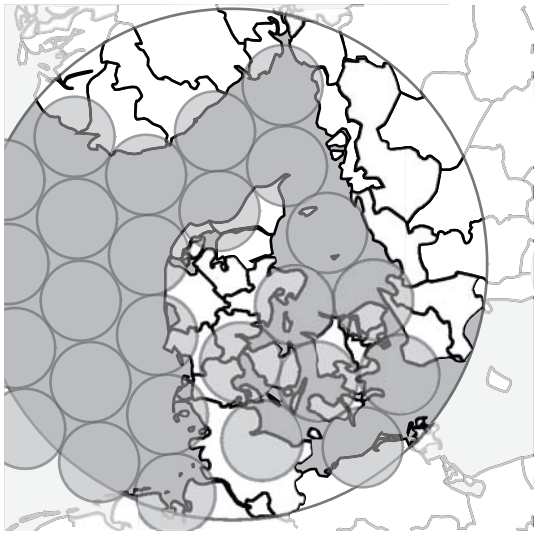

Figure 1.2: Each circle represents a possible ship synchronization zone. When receiveing from high altitude more than one zone will be in the satellites footprint.

An altitude of 35 km will give a footprint radius of approximately 650 km (Appendix I).

Today no AIS receivers is known to be in operation in space. One commercial LEO experiment of lower complexity than the AAUSAT3 AIS receivers exists, but the results are not published, so getting a functional AIS receiver in high altitude will be breaking news [COM DEV International 07].

The expected outcome of the NAVIS project is a test of the AIS systems, collection of raw AIS data and a test of the general AAUSAT3 structure. DaMSA will provide reference AIS data from land based stations in the relevant area for comparison. It is of high scientific interest to get access to raw data as well as test the AIS signal decoding algorithms for both students and researchers at Aalborg University. The data obtained will be further analyzed in master projects as well as by researchers at the university.

1.2.1 Experiment subsystems

The experiment is developed with two different solutions to receive AIS from AIS transponders. This is done for testing how the two different solutions will react due to the climate and to compare the two solutions for further development. Because the two AIS system are redundant, it raises the reparability for a success, even if one of the systems will malfunction. The experiment is divided into the following subsystems:

- Hardware AIS receiver
- Software AIS receiver
- Splitter

- UHF radio
- E-link adapter
- Platform system

This is illustrated in Figure 1.3.

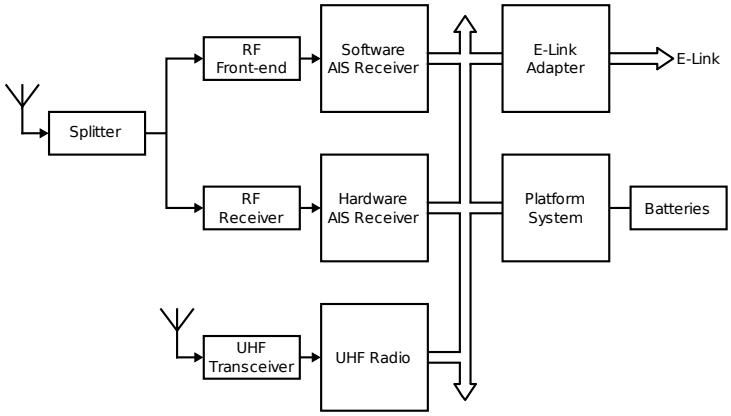

Figure 1.3: System flowchart

In order to keep the system as modular as possible, the internal communication is handled by CAN Space Protocol (CSP), a CAN (Controller Area Network) protocol developed at Aalborg University for use in AAUSAT3. The protocol enables socket-like communication between all subsystems simply by assigning addresses to subsystems and ports to services.

Hardware AIS receiver (AIS1)

The goal of AIS1 is to receive AIS using a well know and thoroughly tested technology. AIS1 consist mainly of a COTS hardware receiver and demodulator. The selected general purpose receiver must be configured both by external discrete components and by software to the right frequency and modulation scheme. This receiver will use an MCU to handle the AIS protocol. More information about the AIS protocol is found in Appendix B.3.

Software AIS receiver (AIS2)

The AIS2 will use a hardware down converter and sample the low Intermediate Frequency (IF) output. A Digital Signal Processor (DSP) is used for filtering and demodulation of the data. This allows advanced demodulation algorithms to be tested and permits in-flight reconfiguration and optimization of the algorithms in space. AIS2 is able to store raw sampled data to be used for development, optimization and algorithms evaluation on ground after the BEXUS flight.

Splitter

The purpose of the splitter is to distribute the received signal from one antenna to the two AIS subsystems. Furthermore, the splitter contains components for amplification and filtering of the signal.

E-Link adapter (ELA)

The ELA acts as a gateway between the BEXUS E-Link, and the internal CAN. By using both E-Link and the AAUSAT3 UHF Transceiver, the experiment will have redundant communication channels.

Platform system

The Platform system will handle battery management, power conversion, distribution and measurements. Furthermore the Platform system will act as a subsystem watchdog timer and enable remote monitoring and power control of the individual subsystems. The subsystem also contains a system log and the flight plan, which can be modified during flight.

UHF Transceiver

The UHF radio is an experiment in itself and is based primarily on the work of a master thesis started in 2008 and ending in may 2009. The thesis focuses on the development of a new radio system for amateur spacecrafts and uses a simple off-the shelf radio platform with new coding techniques to obtain a large improvement over traditional radio systems. Flying the UHF radio on the high altitude baloon will influence the system in ways similar to a low-earth-orbit satellite. The goal of the test is to predict and model the effect of these influences and of course be able to maintain a reliable data-link for telemetry. The system uses the AAUSAT-II's licensed UHF channel at 437.425 MHz using 2FSK modulation.

1.3 Scientific Support

NAVIS has support from a number of individuals associated with Aalborg University and DaMSA. The department of Electronic Systems at the university provides supervision for the two project groups, and Center for Software Defined Radio will assist in the implementation of the DSP software for AIS2. The following people will assist the NAVIS project:

Hans Ebert

Associate professor, Group 09gr650 supervisor.

Ole Kiel Jensen

Associate professor, Group 09gr651 supervisor.

Jens Dalsgaard Nielsen

Associate professor, AAUSAT3 project supervisor.

Jesper A. Larsen

Assistant professor, Assisting AAUSAT3 project supervisor.

AAUSAT3 System Engineering group

A group consisting of project supervisors and students from each participating group in the AAUSAT3 project.

Peter Koch

Associate Professor, Head of Center for Software Defined Radio, Aalborg University.

Muhammad Mahtab Alam

Research Assistant, Center for Software Defined Radio, Aalborg University.

Claus Sølvsten

Contact person at the Danish Maritime Safety Administration.

Daniel Winter Uhrenholt

Employee at Aalborg University. Responsible for mechanical design and construction on the NAVIS project.

Aalborg University

Aalborg University (AAU) offers approx 60 different study programmes and has nearly 14,000 students. Aalborg University Space Center was founded in 2004 by the the Faculty of Engineering and Science. The university was involved in the development of the first danish satellite, Ørsted, which was launched in 1999 and still is operational. The student satellite program has resulted in launch of two Cubesats — one of which is still operartional after more than 1 year in space. Furthermore, students from Aalborg University were highly involved in the European SSETI Express satellite.

- Involved in the Ørsted satellite (launched 1999)
- AAU CubeSat (launched 2003)
- SSETI Express (launched 2005)
- AAUSAT-II (launched April 28th 2008 - Still in operation)

1.4 Similar scientifically projects

AISsat-1

Norwegian satellite developed for AIS surveillance of the Arctic Sea. Expected launch in 2009-2010.
`http://www.spacecentre.no/`

ComDev/CanX-6

Commercial satellite launced April 2008. Reported to be a success in a press release from June 5th 2008, but no results have been published.
`http://www.comdev.ca/`

ESA research

ESA has produced a paper in which the possibility of receiving AIS signals in space is investigated.
`http://www.dlr.de/iaa.symp/Portaldata/49/Resources/dokumente/archiv5/1304_Hoye.pdf`

1.5 Team Organisation

The NAVIS team consists of two groups from Aalborg University, studying 6th semester Communication Technology. Group 1 is developing the hardware based AIS receiver (AIS1) and group 2 is responsible for the software AIS receiver (AIS2). The numbers 09gr650 and 09gr651 refers to the internal group numbers at Aalborg University. All students in the project are from Denmark.

1.5.1 Group 1 - 09gr650 - AIS1

Mads Hjorth Andersen (MH)

Born 1985.

- Media contact person

(a) Mads Hjorth Andersen

(b) Troels Laursen

(c) Nikolaj Pedersen

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Figure 1.4: Portraits of group members from group 1

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- ESA contact person

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(a) Troels Jessen

(b) Jeppe Ledet-Pedersen

(c) Hans Peter Mortensen

Figure 1.5: Portraits of group members from group 2

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- DSP integration
- GMSK demodulation
- Code review

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Hans Peter Mortensen (HP)

Born in 1987.

- System implementation
- Matlab simulations
- DaMSA Contact person

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1.5.3 Others

As part of the AAUSAT3 project, two other students are contributing to the development of subsystems for the NAVIS project:

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6th semester Automation and Control at Aalborg University and is developing the software and Ethernet-CAN protocol for the E-Link Adapter (ELA) in his spare time.
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Johan De Claville Christiansen (JC)

10th semester Networks and Distributed Systems student developing the UHF communication link (COM) for AAUSAT3 wich will also be included in the NAVIS experiment and the communication link will be tested. Johan is developing the UHF subsystem as his masters thesis.
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Jesper Abildgaard Larsen (JAL)

Lecturer at AAU will be assisting with PCB layout.
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Jens Frederik Dalsgaard Nielsen (JDN)

Associate professor at AAU supervisor for AAUSAT3 projekt will be helping with media contakt and general advise.
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1.6 Funding Support

The NAVIS project is sponsored equally by the Danish Maritime Safety Administration and Aalborg University. A total of 3000 EUR is allocated for hardware and PCB production.

1.6.1 The Danish Maritime Safety Administration

> The Danish Maritime Safety Administration(DaMSA) (Danish: Farvandsvæsenet, short FRV) is the approving authority for navigation systems and buoyage in Denmark, Greenland and the Faroe Islands. It is part of the Danish combined Search and Rescue Service organization (SAR) and runs 21 coast-rescue stations. It is a department under the Danish Ministry of Defence. The central administration is located in Søkvæsthuset in Christianshavn in Copenhagen. [Wikipedia]

For more information, visit http://www.frv.dk (danish)

1.6.2 Aalborg University

> Aalborg University supports the project by doubling every subsidies from the business world.

1.6.3 Polyteknik

Polyteknik (North Jutland) has been generous to supply us with a high capacity vacuum pump for AAUSAT-II and AAUSAT3. We believe we have the fastest vacuum pump in a student satellite vacuum chamber north of the Alps.

1.6.4 Thrane and Thrane

Thrane and Thrane has kindly lent us a UAIS-1900 AIS transponder.

1.6.5 Actec

Actec has kindly donated batteries for AAUSAT3-NAVIS Bexus08 flight.

1.6.6 Rubico

Rubico AB has generously sponsored a Blackfin MMC/SD-Daughtercard for the AAUSAT3-NAVIS Bexus08 flight.

We are currently in the process of applying for further funding for upcomming projects and are always open for companies that are interested in helping us. For more information on sponsors, visit`www.space.aau.dk`

Chapter 2

Mission Requirements

This chapter defines all requirements to perform the NAVIS experiment. Requirements for the individual subsystems is shown in appendix A

2.1 Technical Requirements

The experiment will run continuously during the entire balloon flight (Estimated MAX 6 hours). AIS1 stores data from one AIS channel of 9k6 baud, thereby creating the following amount of data on the 2 GB microSD card:

$$D_{\text{ais1}} \approx 6 \text{ hr} \cdot 9600 \, {}^{\text{bit}}/_{\text{sec}} \approx 26 \text{ MB} \tag{2.1}$$

AIS2 stores samples from the In-phase and Quadrature channels of the ADF7020-1, down converted to 200 kHz and each sampled with 12 bit at 1 MSPS. The amount of data created during a 6 hour flight will be:

$$D_{\text{ais2}} \approx 6 \text{ hr} \cdot 24 \, {}^{\text{Mbit}}/_{\text{sec}} \approx 65 \text{ GB} \tag{2.2}$$

AIS2 must save 10 % of this data, so an 8 GB microSD card is enough to save this data. The saved data will be analysed after the flight and used for further processing to optimise the algorithms for data processing of the packets and make the AIS receiver better.

2.2 Functional Requirements

Most data will be evaluated after the BEXUS flight, althrough it is planned to download a bit of data to the ground station using E-Link and UHF to evaluate this live at Esrange.

AIS messages includes a CRC checksum, which allows quick verification of received messages. Futhermore, the Danish Maritime Safety Administration will supply reference data after the flight, which contains ship names (MMSI), position and timestamp [Sølvsten 09]. These will also be used for evaluating received data using a standard PC.

Afterwards, the data is used to optimize the demodulating algorithm developed in MATLAB.

2.3 Operational Requirements

The first AIS message is expected to be received in an altitude of 3.8 km, as the antenna footprint radius in this altitude is approximately 220 km (figure 2.1). The interesting collision of AIS messages is expected to occur from this height and above.

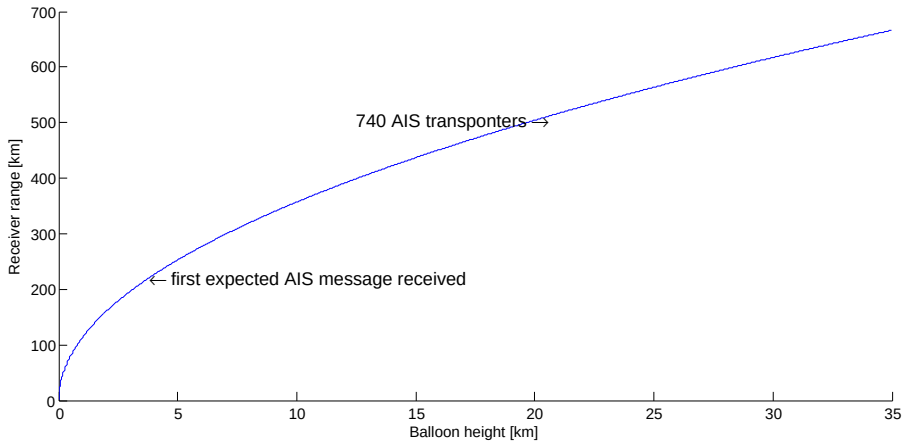


Figure 2.1: Receiver range as a function of balloon height

The minimum required height of the experiment is 20 km, which equals a footprint radius of 500 km. Within this range, there will be more than 500 AIS borne vessels in reach, according to a snapshot from the 5th of February 2009, 10:26:43 UTC there was approxmately 740 ships with AIS transponders in the aeaa of where the ballon flight is done[Sølvsten 09].

If the balloon altitude increases to 35 km, the receiving range will increase to 650 km. With the selected receiving antenna, this gives the field of view shown in figure 2.2. For more information on the pressure and temperature under the flight, see figure 3.15.

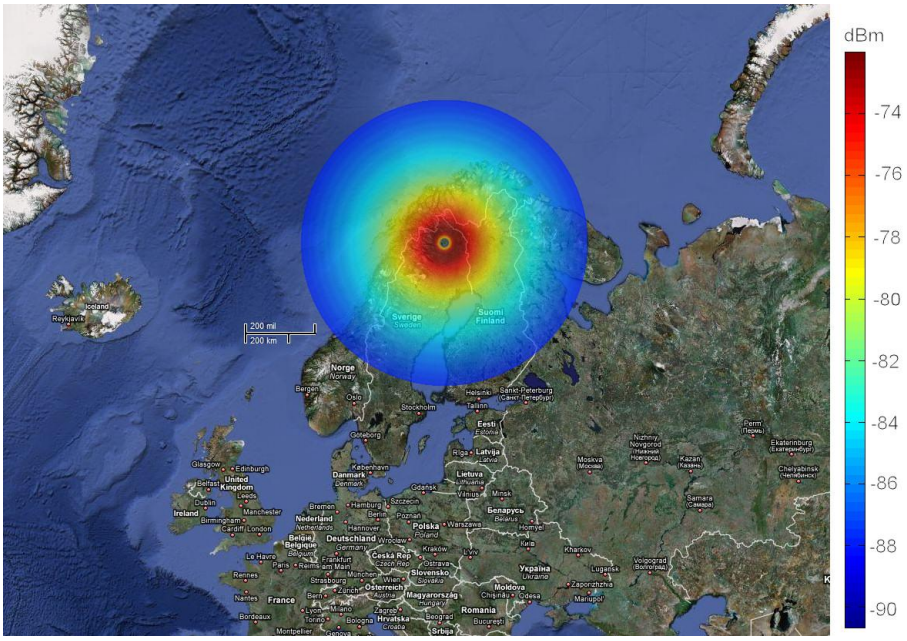


Figure 2.2: Balloon footprint - 35 km height (from appendix I

Chapter 3

Experiment Description

3.1 Experiment Overview

In this section, the functionality of the individual subsystem components is explained. A component budget is also included to give an estimate of the cost of each subsystem. The prices are current market prices from the electronics store `www.digikey.com` quoted 15 March 2009. Some components can only be ordered in large quantities, but the university has good connections regarding this hurdle.

3.1.1 Hardware AIS receiver (AIS1)

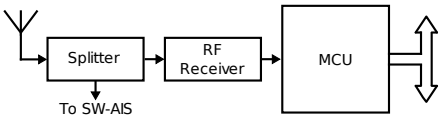


Figure 3.1: Hardware AIS flowchart

RF-receiver
This part consists of an on-chip hardware receiver and demodulator (Analog Devices ADF7021), in daily terms called ADF. This module has to be fitted with certain external discrete components to match the required frequency spectrum, but other parameters like the demodulation type is configured by software through the serial SPI interface. The receiver handles the received RF-signal, from the antenna and through the splitter, and feeds the MCU (Micro controller unit) with a demodulated bit stream through the SPI interface.

MCU
The MCU is receiving the demodulated bit stream from the RF-receiver. The packages are decoded and checked for consistency errors due to packet collision etc. The MCU's final job is to save the received messages on local flash memory and communicate with the other subsystems (E-link and UHF) by using CSP.

Major component costs

Component	Name	Manufacturer	Ordered	Cost [€]
Development platform	AT91SAM7X256-EK	Atmel	yes	170.-
MCU	AT91SAM7X256	Atmel	no	12.-
RF-receiver	ADF7021	Analog Devices	yes	5.-
Low noise amplifier	MAX2371	Maxim	yes	2.-
CAN Transceiver	SN65HVD230	Texas Instruments	yes	3.-
Power splitter	PSC-2-4	Minicircuits	yes	7.-
SAW filter	LBT16201	SipAtSaw	yes	Sponsered
Antenna	KM-3A	Marine	yes	35.-

Table 3.1: AIS1 component economy table

The total cost of the significant components thats is used in this subsystem will be € 64.-.

3.1.2 Software AIS receiver (AIS2)

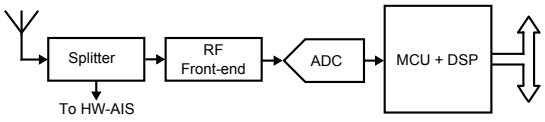


Figure 3.2: Software AIS flowchart

RF front-end
The RF front-end is an on-chip down converter (Analog Devices ADF7020-1), with an output intermediate frequency (I and Q) at 200 kHz and with a programmable bandwidth from 100 to 200 kHz. These frequencies are sufficient for the DSP to demodulate the signal even in case of small frequency drift according to figure 3.3.

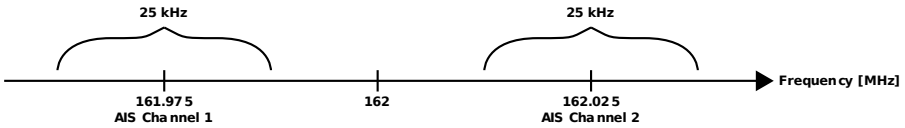


Figure 3.3: AIS frequency spectrum

ADC
The ADC will sample and digitalize the signal and send the digital signal to the MCU.

MCU and DSP
The DSP will demodulate the digital signal. After the signal is demodulated the MCU will decode the AIS packages and check for CRC errors. The MCU's final job is to save the received messages on to local flash memory and communicate with the other subsystems (E-link and UHF) by using the CSP.

Splitter
The RF-signal splitter module amplifies, filters and splits the RF-signal to the two AIS receivers. This is done by the following parts:
LNA: Physically placed near the receiving antenna, a Low-Noise Amplifier (LNA) will amplify the RF-signal from the antenna to improve SNR.

Major component costs

Component	Name	Manufacturer	Ordered	Cost [€]
DSP	ADSP-BF537	Analog Devices	yes	115.-
Radio Front-end	ADF7020-1	Analog Devices	no	4.-
RAM	TBD		no	45
ADC	AD7262	Analog Devices	no	8.-
CAN Transceiver	SN65HVD230	Texas Instruments	yes	3.-

Table 3.2: AIS2 component economy table

BPF: This filter is a surface acoustic wave (SAW) filter, attenuating frequencies outside the desired frequency spectrum.
Power splitter: This passive splitter distributes the RF-signal to the two AIS receivers.

The total price for the significant components in this subsystem will be € 175.-.

3.1.3 UHF Transponder/receiver

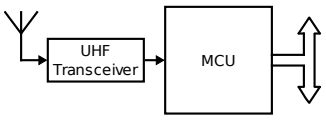


Figure 3.4: UHF transceiver flowchart

Functional Description

The UHF radio interfaces to the other components in the NAVIS experiment through the CSP protocol. This protocol is both a network layer protocol facilitating routing and a transport layer protocol for connection oriented communication. The UHF radio will work like a router, sending CSP packets to and from the ground-segment. The CSP protocol takes care of fragmentation/defragmentation on the CAN bus while the radio must take care of converting data into a proper space-link protocol. The functionalities of the UHF transponder is going to be tested on the Bexus flight to ensure its functionality for use on AAUSAT3 satellite.

Space-link

The recommendations from the *CCSDS 131.0-B-1 TM SYNCHRONIZATION AND CHANNEL CODING* [CCSDS Secretariat 03] is implemented on the space link. This is a preview of the final protocol implementation for AAUSAT3 which will be one of the first cubesats to exchange the old AX.25 protocol with more recent CCSDS recommendations.

One of the main objectives with the UHF radio experiement is to test the performance of the various components in the CCSDS protocol stack. For downlink a $R = 1/2$, $K = 7$ convolutional encoder is used, and for uplink a $K = 3$ encoding will be used, due to the decoding complexity.

For uplink the decoder will be implemented with a hard-decision viterbi decoder which will give an approximate coding gain of 3.5 dB at a BER of $10^(- 5)$. However at higher Eb/No the coding gain will be much larger yeilding a very low bit-error and thus a low packet error rate.

For downlink a $K = 7$ soft-decision viterbi decoder is the goal. This will give a coding gain of up to 6 dB, and make data-communication possible down to about 5 dB Eb/No. This lowers the

requirements to the transmitter output and the ground station antennas. Compared to existing AX.25 / AFSK spacelinks commonly used by cubesats which has a Eb/No requirements of almost 16-20 dB this is a performance gain over an order of magnitude. The balloon flight will give the first real-life performance measurements and help validate the various components of the link-budget.

GENSO coorporation

There is an active collaboration with the GENSO project since (JC) is a GENSO mentor on the hardware interface and protocol layer of the GENSO software platform. There is currently an ongoing effort to implement an FSK software modem that will facilitate soft-decision viterbi decoding. At the time of writing this is the only missing piece of software in order to make GENSO support the new CCSDS framing format that will be used on the UHF radio. The software for the viterbi decoder and CCSDS framer is already completed. This means that there is a good possibility that the GENSO Ground Station Server performance can be tested on the balloon flight as well.

Hardware

The system hardware consists of a computer-platform developed by a student group in the fall 2008 [08gr414 08], a commercial UHF transciever chip (ADF7021) and a power-amplifier. The computer is based on an AVR 8-bit microcontroller and runs the lower layers of the CCSDS protocol stack using convolutional coded forward error correction. The computer interfaces to the transceiver chip via an SPI interface. The transciever also contains a modem and is able to output a directly FSK modulated RF signal at up to 13 dBm. The signal is amplified to about 1 Watt of output power depending on test scenario. A list of components can be seen in table 3.3. The ADF7021 is temperature regulated which means that the output frequency will not deviate more than +300 Hz and -800 Hz from the desired center frequency. The ADF7021 evaluation board has been tested to comply with its datasheet temperature range of -40 deg. celcius to +85 deg. and the microcontroller is tested up to 160 deg.

Component	Name	Manufacturer	Ordered	Cost [€]
MCU	AT90CAN128	Atmel	no	13.-
Radio	ADF7021	Analog Devices	yes	5.
Power Amplifier	SHF-0289	RFMD	no	Free
CAN Transceiver	SN65HVD230	Texas Instruments	yes	3.-
Antenna	NA-702	Nagoya	yes	16.-

Table 3.3: COM-U component economy table

The total price for the significant components in this subsystem (without power amplifier) will be € 37.-. Note that RFMD offers free components for the AAUSAT3 project.

Portable Ground Station

To support the UHF experiement, a ground-station will be needed. This ground station will consist of a relatively small gain handheld yagi antenna on a microphone stand. A LNA will be attached directly on the antenna making it possible to have quite a long cable run to the "mission control center" where the transceiver will be placed. The transciever used on the ground station is the same as used on the experiement.

Description	Value
Max. Experiment TX power	1 W
Max. Ground station TX power	4 W
Max. 3db Bandwidth	25 kHz
Frequency	437.475 MHz
Adjacent channel power	TBD
Harmonics	TBD

Table 3.4: RF caracteristics

RF caracteristics

All communication is held within a reserved satellite frequency band (AAU Cubesat) and harmonics and spurs will be filtered by a harmonics filter, so the ajdacent channel power will not interfer with any other systems.

3.1.4 E-Link adapter

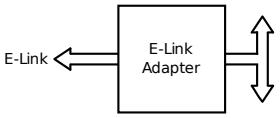


Figure 3.5: E-link flowchart

E-link adaptor.
The E-link is communicating with earth by using the communication link on the balloon provided by BEXUS. The E-Link is also communicating with all the other subsystems by using CSP protocol.

Component	Name	Manufacturer	Ordered	Cost [€]
CPU	AT91SAM7X256	Atmel	no	12.-
CAN Transceiver	SN65HVD230	Texas Instruments	yes	2.-

Table 3.5: ELA component economy table

The total price for the significant components in this subsystem (without power amplifier) will be € 14.-.

3.1.5 Platform system

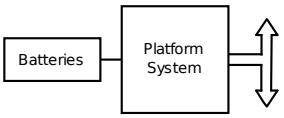


Figure 3.6: Platform system flowchart

This subsystem takes care of all flight planning (activation of the various subsystems) and power distribution of the experiment, and is therefore the most vital part of all the subsystems. The power management includes power distribution with fault detection and battery management.

Batteries
The batteries, which supplies the whole system with all the subsystems, are connected to the MCU.

MCU
The MCU is monitoring the distribution of power to the individual subsystems. The MCU is also responsible of the flight planner. It can communicate and control the power to all the subsystems and thereby shot down and turn on individual subsystems. The MCU is frequently logging the system status.

Component	Name	Manufacturer	Ordered	Cost [€]
MCU	AT90CAN128	Atmel	no	13.-
3.3V DC-DC	TPS62111	Texas Instruments	no	3.-
5V DC-DC	TPS62112	Texas Instruments	no	3.-
I2C Port Expander	MAX7326	Maxim	no	2.-
Real-time Clock	DS1374	Maxim	no	3.-
CAN Transceiver	SN65HVD230	Texas Instruments	yes	3.-

Table 3.6: Platform component economy table

The total price for the significant components in this subsystem will be € 27.-.

3.2 Experiment Setup

3.2.1 Interfaces

Mechanical Interfaces

The system housing consists of a cubesat frame of 10x10x16 cm. The cubesat frame is mounted inside a Experiment box, which is mounted on a BEXUS mounting interface.

Electrical Interfaces

Figure 3.7 shows the connector placement on the end of the Experiment Box. Details on the connector type and pinout are shown in the following tables. The Experiment box has 4 external connectors, one service interface and a remove before flight.

System Status LED The LED will blink with green light when the system is running and the power-on self test has gone through without errors, and will blink red in different error codes if the system has detected any errors. The flight plan will handle the LED.

Remove Before Flight A reed magnetic contact will be used for remove before flight. When the contact is influenced by a magnet, the DC-DC converters in the platform will disable their output. A piece of iron will be placed next to the reed contact to ensure that the magnet will keep in place under transport.

E-Link Interface Panel connector: MIL-C-26482-MS3112E-12-10S. Table 3.7 shows the pinout in according to the Bexus user manual v. 5. Internal the E-link interface is connected to the ELA subsystem.

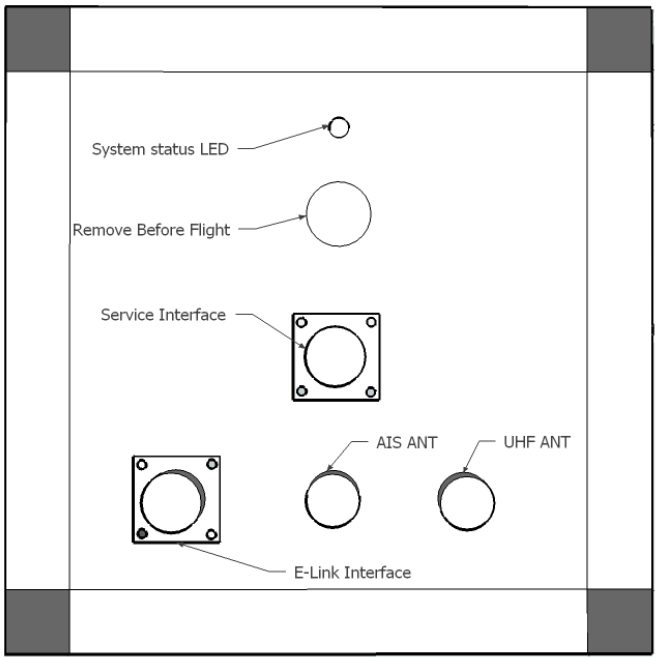


Figure 3.7: Electrical Interface on Experiment Box

E-Link	RJ-45	Cable	Signal
A	1	Pair 1	Tx +
B	2	Pair 1	Tx –
C	3	Pair 2	Rx +
D	4	Pair 3	GND
E	5	Pair 3	GND
F	6	Pair 2	Rx –
G	7	Pair 4	GND
H	8	Pair 4	GND
I			NC
J			NC

Table 3.7: E-Link pinout

UHF Antenna Connector A female N-connector that makes connection to the UHF subsystem.

AIS Antenna Connector A female UHF-connector which makes the internal connection .

Service Connector MIL-C-26482-MS3112E-10-6P Service Connector will be used for debugging, system monitoring and testing via CSP over CAN, and for battery charging. A 6 pin connector is chosen to avoid confusion with the BEXUS power connector, which uses the same type of connector, but with 4 pins. Table 3.8 shows the pinout for the service connector.

Pin	Signal
A	Supply
B	CAN +
C	CAN –
D	GND
E	NC
F	NC

Table 3.8: Service connector pinout

Interface Control Documents

Preliminary Interface Control Documents (ICDs) describing all subsystem commands are located in Appendix C.

3.3 Mechanical Design

3.3.1 Experiment Box

Figure 3.8 shows the experiment box, which have been added since the PDR, due to review panel concerns about thermal and mechanical design. The outer frame allows 50 mm of isolation around the Cubesat frame. The isolation used are firm foam, of the kind normally used for flight cases[Support 09]. The outer frame are build of 20x20 mm structural aluminum, with a material thickness of 1.25 mm, and corners from System Standex A/S (figure 3.9). On all 6 sides of the Experiment Box, aluminum side panels will be mounted, with a material thickness of 1.5 mm.

3.3.2 Bexus Mountings

The Experiment Box will be mounted in the balloon gondola using right-angled structural aluminum. The structural aluminum is 30x30 mm, with a material thickness of 3 mm. The weight is 0.495 $^{kg}/_{m}$, and two pieces with a length of 405.5 mm each is used. The oval-shaped mounting holes (R=5.25 m) allows mounting both on Egon and S-Egon. An illustration of the Bexus mountings are shown on figure 3.10. The outher distance between the two mountings are 209 mm, and therefore the distance between the mounting holes will be

3.3.3 Isolation

Figure 3.11 shows the isolation between the Experiment Box (without side panels) and the Inner frame. For more information about the isolation, see section 3.4.

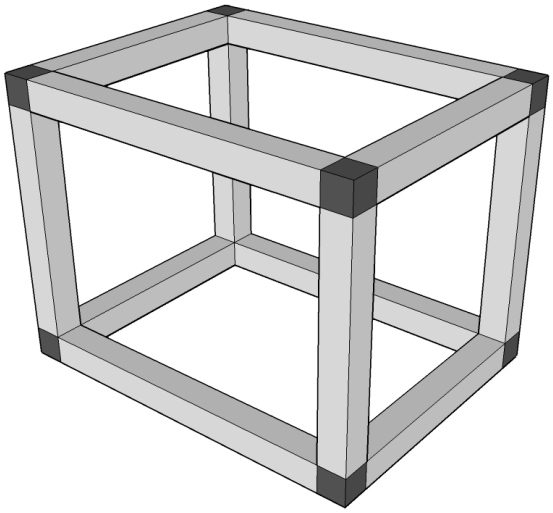


Figure 3.8: Experiment box for mounting of Cubesat frame (200x200x260 mm)

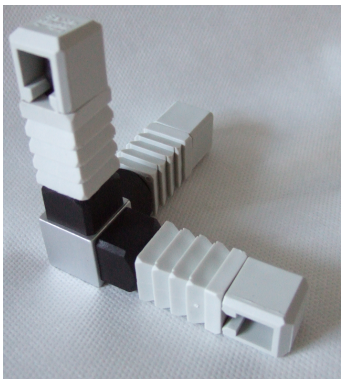


Figure 3.9: Experiment box corners from System Standex A/S

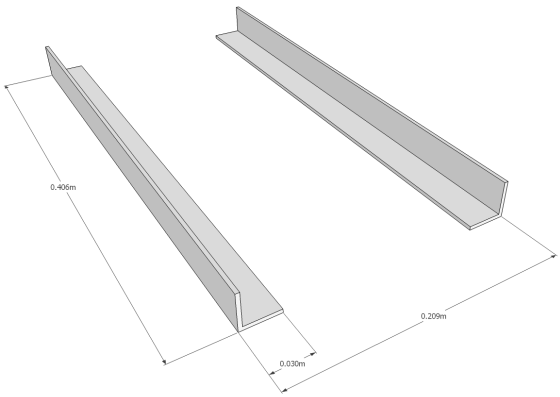


Figure 3.10: Bexus Mountings

Figure 3.11: Isolation between Experiment Box and Inner frame

3.3.4 Inner frame

The experiment electronic will be mechanically mounted inside a extended Cubesat frame to ensure a mechanical robust system. The frame is shown in figure 3.12.

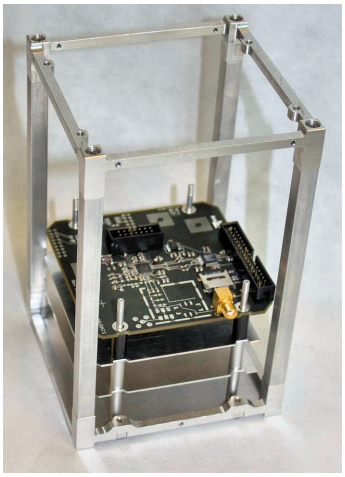


Figure 3.12: Extended Cubesat frame for mounting of PCB's (100x100x160 mm)

3.3.5 PCB outline

Each subsystem (PCB) will be produced in same space quality as AAUSATII PCB's. The mechanical outline for all subsystem is shown in figure 3.13. A stack connector are used to distribute power and connect CAN communication between the different subsystems.

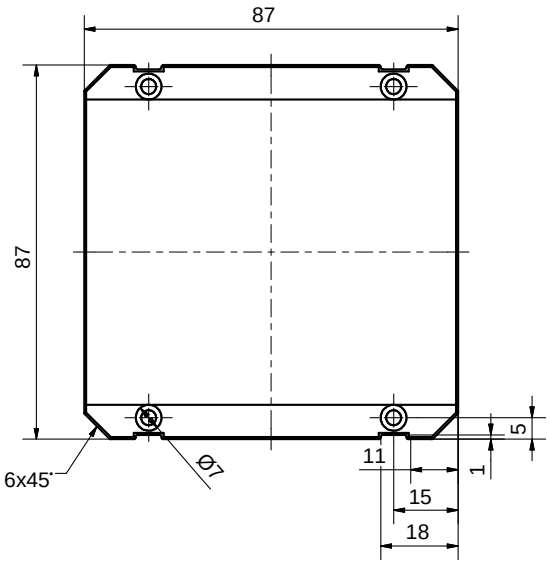


Figure 3.13: PCB mechanical outline (87x87mm)

3.3.6 Antennas and mounting

The experiment contains two external antennas, one VHF dipole (length 110 cm) and a UHF antenna (length 34 cm). Figure 3.14 shows how the two antennas will be hanging in a steel wire beneath the gondola. This allows replacing when working on the balloon on ground. It doesn't matter if the antennas will be destroyed during landing.

3.3.7 Mass budget

An estimated mass budget of the NAVIS experiment is shown in table 3.9. Remark that the masses are estimates only, therefore the 250 g buffer. The weight of PCB's including components originates from AAUSAT-II experiences. The weight budget has increased since SED v1.0, from 1.4 kg to 4.5 kg. This is mainly due to the added Experiment Box and mountings.

3.4 Thermal Design

As seen in section 3.3, the outer frame of the experiment makes room for 5 cm of isolating material. A sort of foam rubber that is normally used to line flight cases is chosen, since it has the mechanical temper so that the cubesat frame does not need specifically mountings to the outer frame that normally will result in a thermal bridge.

To make sure the batteries will supply as expected, it is desired to calculate the power usage necessary for holding an internal experiment temperature of minimum 0 °C. On figure 3.15 the measured temperature from another BEXUS flight is shown.

The mechanic is designed for a insulation thickness, x, of 5 cm. The radiated power is calculated using the law of thermal conduction[Serway 04, p. 624]:

$$P = kA\frac{\Delta T}{x}$$

Where the surface area of the cubesat frame is give by:

$$A = 4 \cdot 0.016 \text{ m}^2 + 2 \cdot 0.01 \text{ m}^2 = 0.084 \text{ m}^2$$

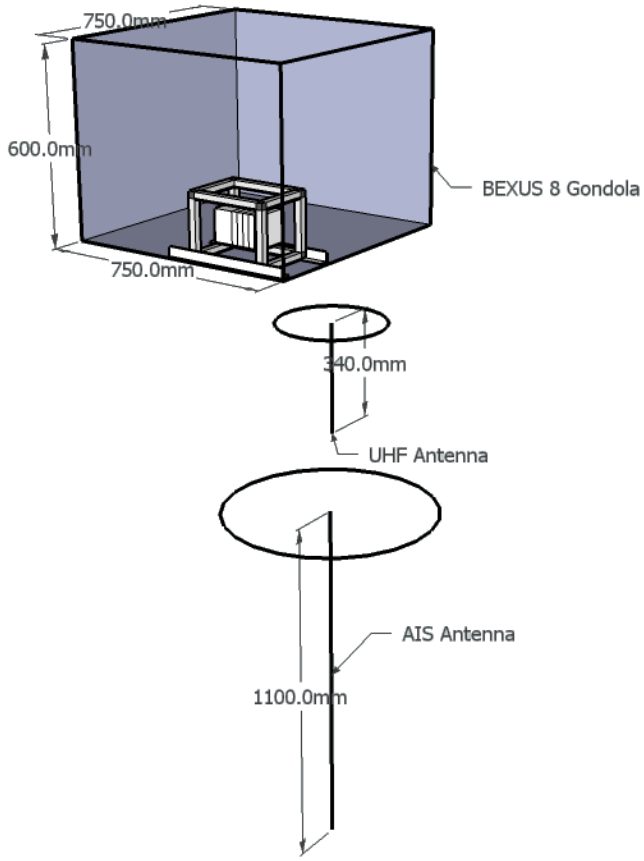


Figure 3.14: Antennas hanging beneath gondola

Component		Weight	
Electronics	Platform	42	g
	6 Batteries	264	g
	AIS-HW	60	g
	AIS-SW	80	g
	ELA	42	g
	Heating	42	g
	PCB shielding	150	g
Mechanics	Cubesat frame	142	g
	Cubesat panels	10	g
	Experiment box	1083	g
	Side panels	1215	g
	Isolation	300	g
	Bexus mountings	500	g
	VHF antenna	210	g
	UHF antenna	150	g
	Buffer	250	g
Total mass		4540	g

Table 3.9: Estimated mass of total experiment

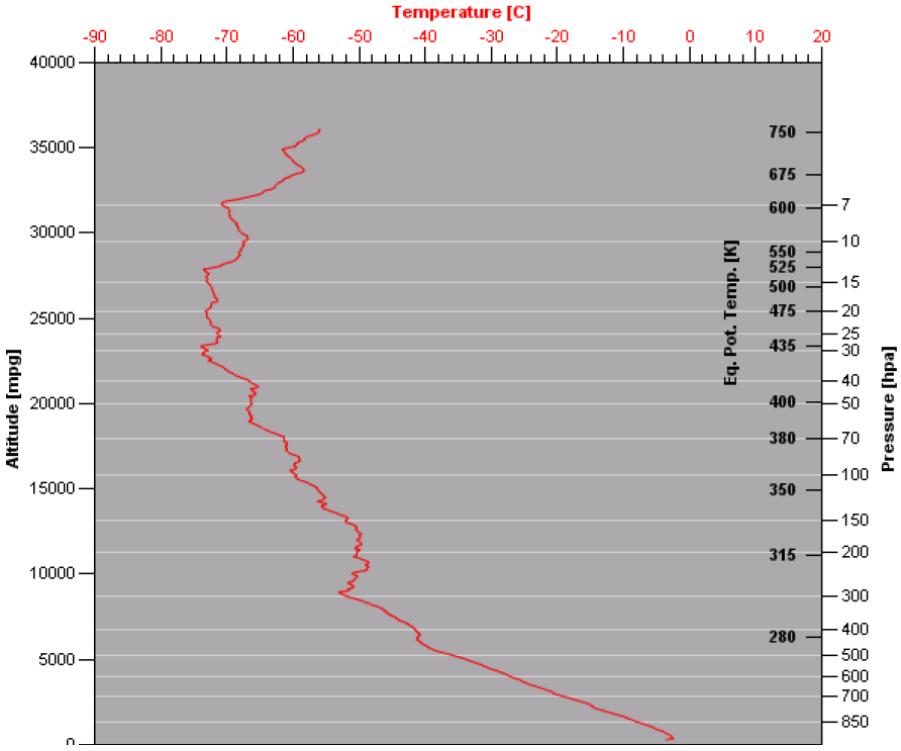


Figure 3.15: Expected temperature for the experiment[SSC 09]

Experiments have shown that the foam rubber has an isolating effect that corresponds to polystyrene, thus k is chosen to be:

$$k = 0.04 \ {}^{\mathrm{W}}/_{\mathrm{m}} \cdot^{\circ} \mathrm{C}$$

The following power is necessary to secure an internal temperature of about 0 °C, when the lowest expected temperature is 70 °C will be:

$$P = 4.7 \ \mathrm{W}$$

This heat will be generated by the subsystems themselves and with effect resistors placed around the batteries. The resistors will be active controlled on the basis of the inner temperature of the experiment. Experiences from AAUSAT-II has shown that the inner heat transport will be sufficient to keep all subsystems within their designed range.

3.5 Power System

The project will include its own battery power supply. The batteries will be six Panasonic CGR18650CF as they have been tested with success on AAUSAT-II and are proved to function excellent in space. The battery pack will have enough power to run all subsystems on an average duty cycle for at least 6 hours. The batteries will be isolated and electrically heated if considered necessary.

Power for each subsystem is managed by the Power Distribution Unit (PDU) located on the platform system. The PDU supplies 3.3 V and 5 V channels, each channel is able to deliver 1 A.

Table 3.10 gives an estimate of the power usage for each subsystem. The power consumption is estimated on a basis of all significant components on the different subsystems. Note that some subsystems has more than one state, which are all described in section 1.2.1. The calculation from

Subsystems	Duty	Active1	Duty	Active 2	Duty	Idle	Average
Platform	15 %	1488 mW	85 %	323 mW	0 %	0 mW	498 mW
AIS1	100 %	455 mW	0 %	0 mW	0 %	0 mW	455 mW
AIS2	100 %	1062 mW	0 %	0 mW	0 %	0 mW	1062 mW
E-Link	15 %	417 mW	85 %	37 mW	0 %	0 mW	94 mW
Total							2109 mW

Table 3.10: Estimated power consumption

Power consumption including heat	4700	mA
Total flight time	6	hr
Nominal apacity per battery	7400	mWhr
Max usage of batteries	70	%
Number of batteries needed	6	

Table 3.11: Battery requirement calculation

section 3.4 is used to compute the number of batteries needed, thus the subsystems themselves will not generate enough heat to fill the requirement found in section 3.4.

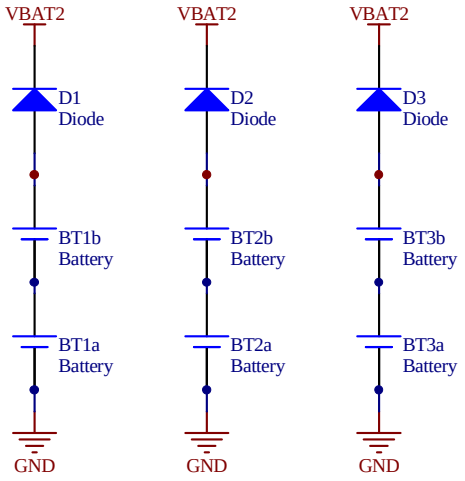


Figure 3.16: Battery package suggestion 1

Two suggestions for the battery package is shown i figure 3.16. The diodes in suggestion 1 are placed for security, such that if one cell in the battery package looses it's voltage, the system will keep running with the remaining cells pairs. Each cell voltage will be measured, such that a cell failure can be monitored and a new flight plan can be initiated. In battery suggestion 2, the protection diodes are removed, which will make a common charge of the batteries, just as the voltage drop over the diodes will be avoided. I return, the batteries will be tested individual prior to flight, just as the build-in security circuit on the batteries will be in place. It is chosen to use battery constellation number 2.

For regulated voltage supplies, two DC-DC converters are used. One (TPS62111) for 3.3 V supply, and another (TPS62112) for 5 V supply. Each capable of delivering 1.2 A. The TPS62111

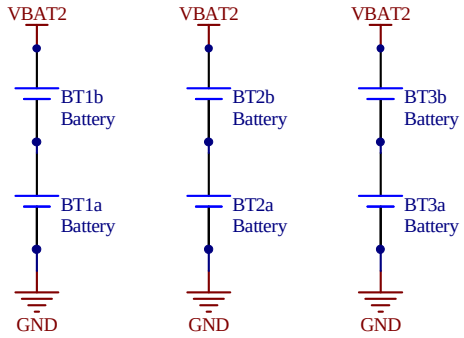


Figure 3.17: Battery package suggestion 2

has been tested for efficiency according to Appendix G.1. This is IC U30 in the attached file `platform.pdf`.

3.6 Experiment Control System

3.6.1 Electronic Design

The experiment will be build as distributed subsystems, each of these with its own CPU.

Subsystem	CPU	Main core	Max Core speed [MHz]
Platform	Atmel AT90CAN128	AVR	16
COM-U	Atmel AT90CAN128	AVR	16
AIS1	Atmel AT91SAM7X256	ARM7TMDI	55
AIS2	Analog Devices ADSP-BF537	Blackfin	500
ELA	Atmel AT91SAM7X256	ARM7TMDI	55

Table 3.12: Central processing units

An overview of the processing units used in the project is shown in table 3.12, with their maximum core frequency. To ensure a minimum power usage, most of the CPU's will run at a lower clock speed than designed for.

3.6.2 Data Management

Up/downlink usage

The experiment will autonomously send system status reports to ground every 30 seconds, containing important information, such as battery voltage and state of the AIS receivers. Downlink of received AIS packages are obvioulsy important as well. Therefore, it is estimated that a 9.6 $^{\text{kbit}}/_{\text{s}}$ downlink is necessary. Uplink will be 1.2 $^{\text{kbit}}/_{\text{s}}$ as the uplink is only used for sending commands from ground to the system. 1 sec of raw sampled AIS data will give about 3 MB of data. Using 9k6 downlink this is approximately 5 minutes of transfer time. It is desired to download this amount of data two times each our and more often if possible. Along with this, decoded position reports will continuous be transferred to ground.

Remark that the experiment will be designed to run autonomously so a ground link is not crucial for the success of the experiment. UDP on the E-Link will be used for additionally communication, along with the UHF communication included in this experiment.

Data storage

Data will be logged redundantly on the BEXUS flight, partly using NOR flash (SPI interface) and Kingston 2GB microSD card. The AIS2 subsystem is fitted with two Kingston microSD cards, for logging of raw sampled data. The 8 GB available space will be used for periodic logging of raw data. Beyond that, the 9.6 kbit/s binary data will be simultaneously logged (ca. 26 MB) for further investigation after the flight. The Kingston SD cards are rated operational from -25 to 85 deg C.

Subsystem	Storage
AIS1	16 MB SPI NOR flash
	16 MB SPI NOR flash
	2 GB SD NAND flash
AIS2	8 GB SD NAND flash

Table 3.13: Available storage

3.6.3 Radio Frequencies

The two AIS subsystems will receive signals transmitted on Marine VHF channels AIS1 and AIS2 (not to confuse with the subsystems with same names) at 161.975 MHz and 162.025 MHz.

The COM-U subsystem will be transmitting and receiving on UHF frequency 437.425 MHz. This channel is licensed to Aalborg University and is also used for AAUSAT-II with callsign OZ2CUB. The subsystem will transmit with maximum 1 W. The speed will be varying from 1k2 to 9.6 kbit/s. The ground station will transmit at maximally 50 W. In order to avoid interference with systems at Esrange, the ground station can be placed away from the control room and remote controlled. The antennas on ground will be a Yagi-Uda antenna array with a remote controlled rotor. The position of the balloon will be supplied from BEXUS.

3.7 Economy

In this section, the overall economic situation is stated.
The major component expense is a total of € 185.-. This expense will be doubled because two even versions of the experiment will be produced - one for testing and one for flight. However the major expense is the manufacturing of 4-layer PCB's for the subsystems. The expense of 3 even PCB's is € 335.-. The number of PCB's are 4. Discrete components, accessories for building the systems and mechanical components will be provided by the university. The estimated total expenses are are shown in table 3.14.

Subsystem	Cost [€]
2x Platform	50.-
2x UHF	74.-
2x AIS1	128.-
2x AIS2	175.-
2x ELA	28.-
PCB's (4x335.-)	1340.-
Total:	**1795.-**

Table 3.14: Economy of the project

Chapter 4

Review and Test

4.1 Experiment Selection Workshop (ESW)

At the ESW, the presentation named `esw_presentation.pdf` in this folder was shown. After the presentation, the following comment was received:

You should assess the footprint of your system and the estimated number of ships present in the area during the launch campaign in October.

It is planned that the comment will be accounted for in this SED and at the PDR.

4.2 Preliminary Design Review (PDR)

The comments from the PDR is located in Appendix J.

4.3 Test Plan

To test the selected system platform for space and balloon flight fitness, the system must undergo a number of tests. The primary concerns are thermal design and vacuum/thermal stability. Therefore two tests are performed.

- A thermal stress test is performed, where the system is exposed to temperatures from -40 degC to +85 degC while executing a program. Throughout the test the temperatures on the MCU and the ADF radio chips are monitored, frequencies of both MCU system clock and ADF radio TXCO clock is logged, and the test data stream from the received data on the ADF is monitored for errors.

- A vacuum test is performed to test if any components are fragile to this environment and to observe the thermal behavior of both the MCU and the ADF radio chips. In this test the chip temperatures on both chips are monitored and logged while letting the system process test data generated from a GMSK signal modulator and outputting them on the RS232 serial port of the MCU. Any errors or unexpected behavior is monitored and logged.

Many other tests has been done but not yet documented, the result of these will be presented and discussed at the CDR.

4.4 Critical Design Review - CDR

This document contains the documentation for the CDR.

4.5 Experiment Acceptance Review - EAR

Chapter 5

Project Planning (Phase B and C)

5.1 WBS - Work Breakdown Structure

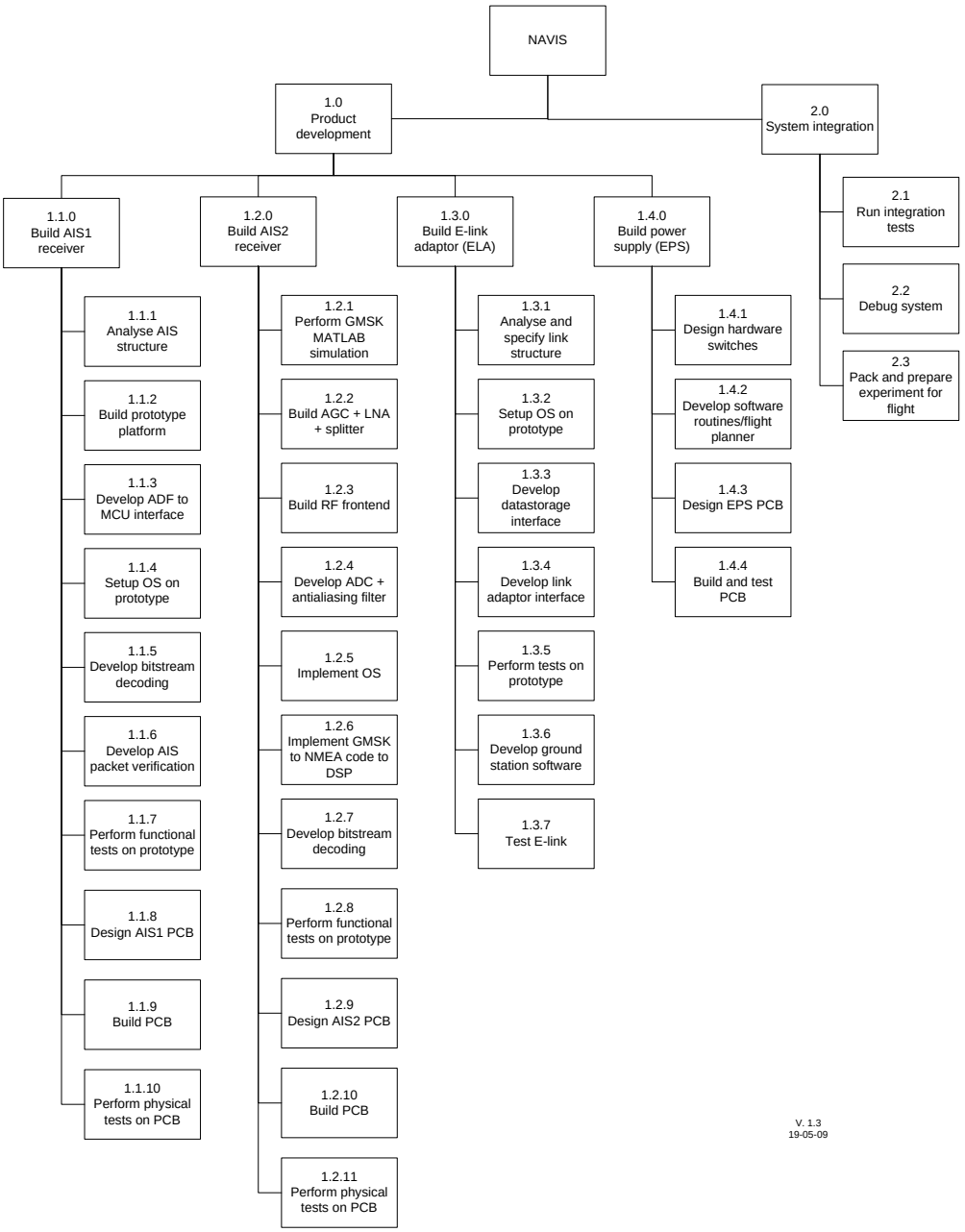

NAVIS
1.0 Product development
2.0 System integration
1.1.0 Build AIS1 receiver
1.2.0 Build AIS2 receiver
1.3.0 Build E-link adaptor (ELA)
1.4.0 Build power supply (EPS)
2.1 Run integration tests
2.2 Debug system
2.3 Pack and prepare experiment for flight
1.1.1 Analyse AIS structure
1.1.2 Build prototype platform
1.1.3 Develop ADF to MCU interface
1.1.4 Setup OS on prototype
1.1.5 Develop bitstream decoding
1.1.6 Develop AIS packet verification
1.1.7 Perform functional tests on prototype
1.1.8 Design AIS1 PCB
1.1.9 Build PCB
1.1.10 Perform physical tests on PCB
1.2.1 Perform GMSK MATLAB simulation
1.2.2 Build AGC + LNA + splitter
1.2.3 Build RF frontend
1.2.4 Develop ADC + antialiasing filter
1.2.5 Implement OS
1.2.6 Implement GMSK to NMEA code to DSP
1.2.7 Develop bitstream decoding
1.2.8 Perform functional tests on prototype
1.2.9 Design AIS2 PCB
1.2.10 Build PCB
1.2.11 Perform physical tests on PCB
1.3.1 Analyse and specify link structure
1.3.2 Setup OS on prototype
1.3.3 Develop datastorage interface
1.3.4 Develop link adaptor interface
1.3.5 Perform tests on prototype
1.3.6 Develop ground station software
1.3.7 Test E-link
1.4.1 Design hardware switches
1.4.2 Develop software routines/flight planner
1.4.3 Design EPS PCB
1.4.4 Build and test PCB
V. 1.3
19-05-09

Figure 5.1: NAVIS work breakdown structure.

5.2 Time Schedule Of The Experiment Preparation

The time schedule is implemented in a Gantt chart, see attached file: `Time_schedule_v2.pdf` which is also included in the end of this document.

5.3 Resource Estimation

The timewise resources available in 2009 for the project are limited by primarily two factors: Number of people assigned to the project groups and number of semester courses attended by the group members. A week is rated as 45 working hours per student, from which the courses must be deducted. These courses are placed in Q1 which is reflected in table 5.1.

During the semester all project members (7) will be available full time, but during the summerholydays (July and August) the resources will be limited. There will also be limited resources available during June, due to semester exams and evaluations.

Project work is therefore expected to be minimal during this month. In september the group members will start a new semester which also results in very limited resources for the project. The actual availability is however strongly dependant on which projects are chosen by the project members and is therefore to be determined later in the project. The total estimated resources, available for the project, are stated in the following scheme:

	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	**Total**
Resources pr. student [hr]	70	70	135	190	40	210	190	TBD	**905**
Total resources [hr]	490	490	945	1330	280	630	570	NA	**4735**

Table 5.1: NAVIS project resources

The critical part of the development will take place in July and August. In this period the project members are working voluntarily on the project and therefore a detailed resource estimation has been calculated based on a availability assessment from each team member. This assessment is stated in table 5.2

During July and August each team member has been assigned to specific tasks on the subsystems in order to manage the resources and to secure the follow-up on each system. This assignment is stated in table 5.3 for July and table 5.4 for August.

Person	Percentage	July [hr]	August [hr]
TL	40%	64	59
NP	80%	129	118
MH	20%	32	29
UW	20%	32	29
JL	80%	129	118
TJ	25%	40	37
HP	80%	129	118
JC	50%	81	74

Table 5.2: NAVIS project member resources during summer holidays.

Subsystem	Members	TL	NP	MH	UW	JL	TJ	HP	JDC	**T**otal July
AIS1	NP, MH, UW, TL	64	129	17	32					242
AIS2	JL, TJ					129	40			169
MECH	HP							29		29
ELA	AB, MH			15						15
UHF	JC								60	60
GND	JC, JAL								21	21
EPS	HP							100		100
In + FP	NP, HP, JC, MH									0
Total		64	129	32	32	129	40	129	81	636
Available		64	129	32	32	129	40	129	81	636

Table 5.3: NAVIS project subsystem resource assignment, July.

Subsystem	Members	TL	NP	MH	UW	JL	TJ	HP	JDC	**T**otal August
AIS1	NP, MH, UW, TL	59	28	17	29					133
AIS2	JL, TJ					118	37			155
MECH	HP							30		30
ELA	AB, MH									0
UHF	JC								35	35
GND	JC, JAL								39	39
EPS	HP							48		48
In + FP	NP, HP, JC, MH		90	12				40		142
Total		59	118	29	29	118	37	118	74	582
Available		59	118	29	29	118	37	118	74	582

Table 5.4: NAVIS project subsystem resource assignment, August.

TL	Troels Laursen
NP	Nikolaj Petersen
MH	Mads Hjorth Andersen
UW	Ulrik Wilken Rasmussen
JL	Jeppe Ledet Pedersen
TJ	Troels Jessen
HP	Hans Peter Mortensen
JDC	Johan de Claville Christiansen

Table 5.5: Members abbreviations

5.4 Hardware and Software Development and Production

5.4.1 Hardware

AIS1

Development boards of both the ADF radio and the MCU has been tested and verified in thermal- and vacuum tests and is working. PCB layout for the flight model has been designed but needs reviewing and production.

AIS2

Blackfin DSP is currently running on development board. AD converters and ADF down-converter has been implemented on a custom PCB and is working. PCB for DSP needs development.

UHF communication link (COM)

MCU platform is running, with ADF radio on development board excluding amplifier. PCB for this system needs to be developed.

Platform system (EPS)

MCU platform is running on rev. 1 PCB. PCB for power supply part and subsystem switches needs to be developed. This PCB should also include MCU platform rev. 2

E-link communication (ELA)

MCU platform is running on evaluation board with ethernet working.

Radio front-end (RFF)

LNA has been tested and is working. AIS2 front-end PCB has been designed to include SAW filter and splitter, but SAW filter has not yet arrived The receiver is therefore tested without SAW filter, which is working. It is still planned to mount the SAW filter when it arrives.

Appendix E includes schematics and PCB layout of AIS1 and AIS2.

BEXUS mechanics (BME)

The mechnical subsystem has been designed. The final sticks to carry the PCBs is to be produced, when its length is finally designed.

5.4.2 Software

AIS1

Operating system on platform is running with ADF radio communication working. Flash storage and CAN driver needs development.

AIS2

Functional algorithms for GMSK demodulation and NRZI decoding are implemented in MATLAB. The uClinux distribution is running on the Blackfin, with example code and SD card I/O working. High-speed serial port (SPORT) for ADC data acquisition and ADF7020-1 device driver needs development.

UHF communication link (COM)

All functional requirements are met, except CAN bus communication. ADF7021 drivers and CSMA MAC protocol done. FEC (r=1/2), Viterbi (K=3) and Reed–Solomon (255,223) implemented. RTOS integration done. Software will be finished in June.

Platform system (EPS, LOG, FP)

Functional prototypes of EPS, LOG and FP was implemented in the spring of 2008. Additional work is needed in the summer holiday, in order CSP protocol. JC has been assigned this task.

E-link communication (ELA)

ELA will use the same CAN driver as AIS1. TCP/IP needs work by ABB in the summer holiday.

5.5 Risk Management

In this chapter you will find the following five most important risk analyses:

- Battery failure
- SW failure
- PCB failure / design-error
- UHF subsystem not ready
- Radio front-end not usable

In general the NAVIS team try to eliminate the most risks by thorough testing, and by building both a Engineering Model (EM) and a Flight Model (FM). The testing facilities includes mainly vacuum chamber and climate chamber.

5.5.1 Battery failure

ID	I/M - 01
Name	Battery failure / explosion
Consequences	No experiment data. Possible personal/balloon damage
Severity	5
Probability	1
Total Risk	5
Prevention	Correct and careful usage of batteries
Reaction	Change possible damaged parts of the experiment
Recovery	

The Platform system, including EPS (Electric Power Supply), will monitor temperature, current and voltage of each battery, and will shut down the system if a critical situation occurs. Furthermore, tests will be preformed to ensure that the batteries can handle the expected environmental impacts. If nessesary the batteries will be isolated and electrically heated.

5.5.2 SW failure

ID	I - 02
Name	SW failure
Consequences	No experiment data.
Severity	5
Probability	2
Total Risk	10
Prevention	Thorough tests. Code review.
Reaction	EPS will be able to reboot subsystems.
Recovery	

5.5.3 PCB failure / design-error

ID	I - 03
Name	Defect PCB
Consequences	Parts of the system fails
Severity	2
Probability	3
Total Risk	6
Prevention	Doublecheck all layouts before production, and make in-house PCB's of the different modules in the experiment
Reaction	Make a hack on the PCB to find a possible solution
Recovery	Fix the error in the layout, and order new PCB's

Aalborg University have one week PCB delivery time. Also, it has been decided to use 4-layer PCB. Two inner layers for GND and supply, and the two external layers for nets. This allows quick "hack" to test functionalities.

5.5.4 UHF subsystem not ready

ID	I - 04
Name	COM-U misses deadline
Consequences	Redundant communication will not be present
Severity	2
Probability	3
Total Risk	6
Prevention	It is a master thesis, so it is expected that the project will be finished, although the NAVIS team does not have much influence in this development
Reaction	The system will be changed so that only the E-Link will be used
Recovery	

5.5.5 Radio front-end not usable

ID	I - 05
Name	Small sensitivity with ADF7020-1 front-end
Consequences	The software-based receiver will not be able to decode the signals from it's frontend
Severity	3
Probability	3
Total Risk	9
Prevention	A test must be made to conclude if the I/Q signal is strong enough to be sampled without errors
Reaction	A new front-end must be designed
Recovery	

A new front-end design will take more time, which will make the schedule tight.

Chapter 6

Outreach Program

The outreach of the BEXUS flight consists of several elements

- The development of the AIS1 and AIS2 receivers will be documented in two publicly available bachelor project reports in spring 2009.
- A scientific article with results and experience gained from the BEXUS flight will be produced in fall 2009.
- At least 4 presentations per year about the AAUSAT3 project for students in high schools and universities.
- The AAUSAT3 website at `aausat3.aau.dk` will be updated with news.
- The NAVIS website at `http://www.navis-project.eu`

The student satellite projects at Aalborg University generally have a good relationship with national media, including major newspapers and television channels.

6.1 Presentations

May 5th, 2009: Associate Professor and AAUSAT3 project supervisor Jens Dalsgaard Nielsen, will present the Aalborg University Student Satellite program at "Folkeuniversitetet".

May 19th, 2009: Jens Dalsgaard Nielsen; "Satellite activities at Aalborg University, Students and Space", Seminar about Software Defined Radio in Satellite Applications, Danish Technological Institute and CSDR.

6.2 Articles in national newspapers

January 15, 2009: Article in the national danish newspaper Jyllands-Posten about the progress of developing AAUSAT3 and its subsystems – `http://jp.dk/arkiv/?id=1570884`

6.3 Workshop and lectures

6-7 April 2009 in Würzburg Germany: NATO, RTO workshop about "Small Satellite Formations for Distributed Surveillance: System Design and Optimal Control Considerations"

Chapter 7

Launch Campaign

7.1 Experiment Preparation

7.1.1 Team organization

The NAVIS team at the launch campaing will consist of 10 persons, each responsible for particular parts of the experiment. The responsibilities during the launch are stated in table 7.1. Furthermore pre- and post launch responsibilities are stated in table 7.2.

Team member	**Responsibility**
MH	Mission Manager *In charge of the experiment procedures and mission coordination*
HP	General system supervisor *Responsible for the ground station operations, including DB/Elink computer*
TJ	Telecommand operator *In charge of the experiment telecommand transmissions*
UW	AIS data analyst *Responsible for analyzing AIS experiment data during flight*
NP	AIS data analyst *Responsible for processing of experiment data during flight*
TL	AIS1 system operator *In charge of the AIS1 experiment flight plan*
JL	AIS2 system operator *In charge of the AIS1 experiment flight plan*
JC	UHF-link manager *In charge of UHF wireless link stations and link operations*

Table 7.1: Team organization during flight.

7.1.2 Timeline

7.3 shows the main events for the NAVIS team, at the Bexus launch campaign. Day one will be spent on accommodation, installation of equipment and on physical inspection of the experiment. If possible the initial test will be done at day 1. Day two will be spent on physical and electrical integration on the gondola followed by th RF interference test and the Flight Simulation Test. Day 3 - 7 will, when the launch is initiated, be spent on monitoring and controlling the experiment.

Team member	Responsibility
MH	Flight preparations supervisor
HP	Mechanical integration
TJ	Electrical and EMC tests
TL	Ground station installation
JL	Ground station installation
UW	E-link and connections
NP	UHF-link
JC	UHF-link
JDN	PR supervisor
JAL	AAU representative

Table 7.2: Team responsibilities for pre- and post flight operations.

Day 7 will be spent on securing data and removing experiment from the recovered gondola. Furthermore the equipment will be packed up and the workspace will be cleaned.

Day 1	*Start of campaign* Safety briefing and general information **Equipment installation** **Experiment post transport inspections**
Day 2	**Experiment preparation and testing** RF interference Tests Flight Simulation Test Flight Readiness Review Pre-flight meeting
Day 3-7	Possible launches
Day 7	Evaluation of data Post flight meeting Cleaning of workplaces **Dismantling and pack-up of experiment** **Equipment pack-up** Campaign dinner

Table 7.3: Bexus launch campaign overview

7.1.3 Operational procedures

For the events stated in table 7.3 procedures has been devised. The procedures includes an overall test procedure, which links to the EPS failure handling. If a subsystem fails during any tests the hardware module is exchanged with a spare. Figure 7.1 shows procedures for initial test, RF test and Flight Simulation Test, respectively. For the **experiment recovery** the helicopter pilot will have to re-attach the remove before flight (RBF) connector on the experiment to ensure a complete experiment shut down. Drawing of placement on experiment will be available at the time of launch.

7.1.4 Launch and flight schedule

Table 7.4 states the NAVIS experiment launch procedure.

Time (h:min)	Action
T-3:00	Experiment pre-flight test
	E-link test
	UHF-link test
T-1:30	Connect service cable for pre-heating heating
T-1:10	Experiment prep. finished. Go from NAVIS team
T-0:40	Experiment service cable for pre-heating removal
T-0:15	Ground station operational and fully staffed
T=0:00	Lift off
T+n:00	Team operation meeting every n=1:5 hours
T+6:00	Experiment automated shut-down

Table 7.4: NAVIS experiment launch procedure

7.2 Experiment Time Event During Flight

When the remove before flight connector has been removed for one minute the experiment enters flight mode where AIS data is stored on both AIS1 and AIS2 memory cards. During the flight the ground station receives status from each AIS receiver with data statistics. The ground station requests ongoing download of data from the experiment when the status from the receivers returns positive packages received. The data is then downloaded to the ground station data base, for analysis, which is handled by the AIS data analysts. The experiment will log data on to the on board flash storage during the whole flight. The UHF link by default sends beacons every 30 seconds, but the ground station can request download of experiment data through this link, primarily to test UHF link quality. Every hour the ground station team gathers for a status meeting to determine any changes in the flight plan and to get a briefing from the experiment supervisors. The experiment flight planner will automatically shut down the experiment after 6 hours.

7.3 Operational Data Management Concept

On figure 7.2 the database ground station data management system is showed. The UHF radio and the E-link communicates with the Data Base computer. All the data and communications with the balloon is stored in the data base and can be read from other computers by requesting it from the data base trough a LAN. The Tele Command computer can send commands trough the Data Base to the required subsystem on the balloon. The Tele command can for example send a request for AIS data using E-link and then all the requested data will be stored in the Data Base which then can be accessed by a request computer via LAN.

7.4 Flight Readiness Review - FRR

7.5 Mission Interference Test - MIT

7.6 Launch Readiness Review - LRR

7.7 Inputs For The Flight Requirement Plan - FRP

7.7.1 Requirements On Laboratories

We will bring our own test equipment, spare parts and all tools needed for integration of the experiment, so laboratory access is not required.

7.7.2 Requirements On Integration Hall

Three tables are needed; one for experiment integration, one for test equipment and one for general use. 10x230 V power outlets are needed for test equipment. If possible, an internet connection would be preferred. We will bring our own test equipment, spare parts and all tools needed for integration of the experiment. No consumables are needed from EuroLaunch.

7.7.3 Requirements On Trunk Cabling

Refer to Requirements On Launcher.

7.7.4 Requirements On Launcher

One 230 V cable from Block House to Launcher is needed for battery charging and pre-heat of the experiment. The experiment requires minimum one hour of pre-heating before launch, and the battery charger should be connected to up until 30 minutes before launch. When charging the batteries, it is desirable to monitor the experiment. If the E-Link is not active pre-launch, a single Ethernet cable is required for monitoring.

7.7.5 Requirements On Blockhouse

If possible, the NAVIS Mission Control Center will be located in the scientific center.

7.7.6 Requirements On Scientific Centre

Tables are required for seven persons: Monitor PCs for AIS1, AIS2 and COM, a general System Monitor, a Command Client, a Ground Station Contact and a Mission Manager. If possible, our portable ground station(section 3.1.3) will be set up near Esrange or, if allowed, inside the facility. An Ethernet link for communication and data between the NAVIS Mission Control Center and the portable ground station is needed.

7.7.7 Requirements On Countdown (CD)

The battery charger should be disconnected 30 minutes prior to CD. Tower access is not needed during CD. On aborted launch procedure, the Ground Station will issue a command to disable the default flight plan, and put the system in idle state (No TX). The experiment has no requirement to a latest hold in CD.

7.7.8 List Of Hazardous Materials

No hazardous materials will be used in the experiment.

7.7.9 Requirements On Recovery

The experiment will stop transmitting beacons after 6 hours. No special requirements for recovery.

7.7.10 Consumables To Be Supplied By Esrange

No need for consumables from Esrange.

7.7.11 Requirement On Box Storage

We will bring our own test equipment, spare parts and all tools needed for integration of the experiment.

7.7.12 Arrangement Of Rental Cars & Mobile Phones

A rental car will be preferred for transporting equipment and persons to the Integration Hall and Scientific Center. Three mobile phones or hand-held radios for team communication is preferred.

7.7.13 Arrangement Of Office Accommodation

No offices are required. Access to a meeting room will be preferred depending on the facilities in Scientific Center/Integration Hall.

7.8 Post Flight Activities

After flight, data that has come through the radio links will be backed up to an external server. The ground station and the systems used for communicating will be taken down, and the arrival of the experiment will be awaited. When the experiment arrives, the content of the storage cards will be copied to a PC through a USB card reader, and this data will be backed up too.

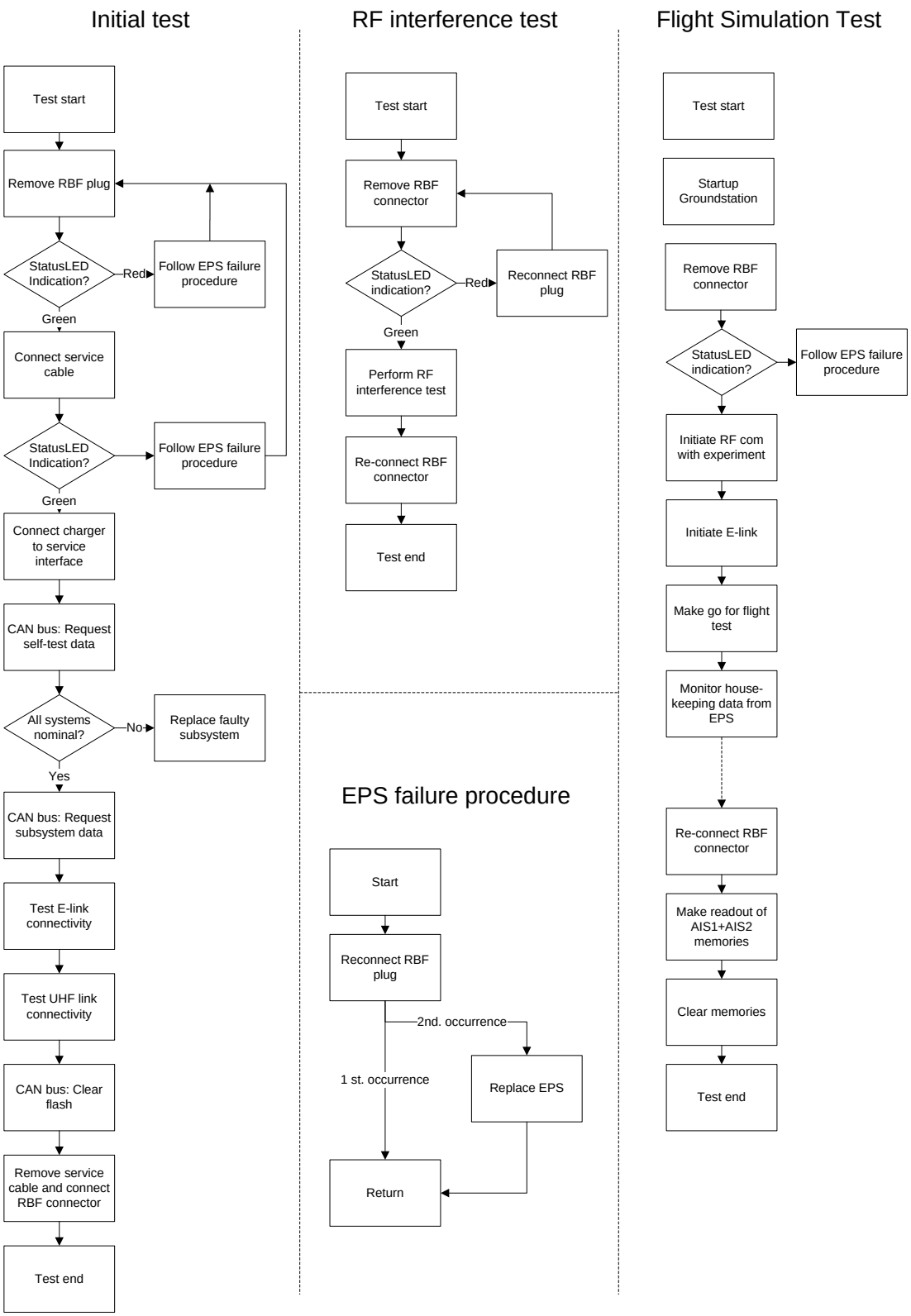


Figure 7.1: Overall pre-launch procedures

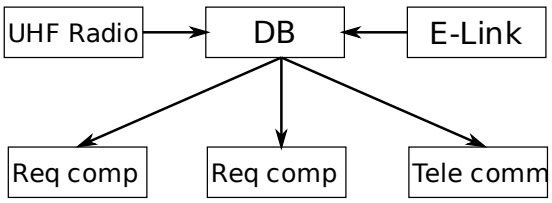


Figure 7.2: Block diagram showing the Database system

Chapter 8

Experiment Report

8.1 Launch Campaign

8.2 Results

8.3 Outreach Activities

8.4 Lessons Learned

Chapter 9

Abbreviations and References

9.1 Abbreviations

ADC	Analog to Digital Converter
ADF	ADF7021 Radio transciever
AGC	Automatic Gain Control
AIS	Automatic Identification System
BER	Bit Error Rate
BPF	Band Pass Filter
CAN	Controller Area Network
CDR	Critical Design Review
CSDR	Center for Software Defined Radio
CSP	CAN Space Protocol
DaMSA	Danish Maritime Safety Administration
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DSP	Digital Signal Processor
ELA	E-Link Adaptor
EPS	Electronic Power Supply
ESA	European Space Agency
Esrange	European Sounding Rocket Launching Range
ESTEC	European Space Research and Technology Centre, ESA
ESW	Experiment Selection Workshop
FPL	Flight Planner
FSK	Frequency Shift Keying
GENSO	Global Educational Network for Satellite Operations
GMSK	Gaussian Minimum Shift Keying
LNA	Low-Noise Amplifier
LOG	Logging subsystem
LRR	Launch Readiness Review
MCU	Micro Controller Unit
NMEA	National Marine Electronics Association
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PFR	Post Flight Report
RTOS	Real Time Operating System
SAW	Surface Acoustic Wave
SED	Student Experiment Documentation
SNR	Signal to Noise Ratio

SSC	Swedish Space Corporation (Eurolaunch)
STW	Student Training Week
T	Time before and after launch noted with + or -
TBD	To be determined
UHF	Ultra High Frequency
VHF	Very High Frequency

Chapter 10

Attachments

`esw_presentation.pdf`: The presentation used at the ESW
`pdr_presentation.pdf`: The presentation used at the PDR
`Time_schedule_v1.pdf`: Gantt chart describing tasks and resources (03-15-09)
`Time_schedule_v2.pdf`: Gantt chart describing tasks and resources (05-24-09)
`platform`: Schematics for the platform system
`SAM7x_basic`: MCU schematics for AT91SAM7X256 CPU
`SAM7x_io`: MCU schematics for AT91SAM7X256 CPU
`pdu.pdf`: Power Distribution Unit
`switch.pdf`: Switch used in pdu.pdf
`ais2_frontend.pdf`: Schematics for the AIS2 frontend and ADC

All attachments is included at the end of this document.

Appendix A

Subsystem requirements

In this appendix, the requirement specification for the individual subsystems is presented. Some requirements are defined before this semester, which is why the structure of the presentation can be different.

A.1 EPS

The EPS must:

1. be able to supply 1 A @ 3.3 V
    - Stable means that a load on 1 A will impact the regulated voltage less than 0.2 V, a ripple on 0.5 V in maximally 1 ms is accepted.
    - The voltage convertion must stop when the battery voltage is 6.0 V and start automatically when the voltage is 6.2 V
2. be able to supply 1 A @ 5 V
    - Stable means that a load on 1 A will impact the regulated voltage less than 0.2 V, a ripple on 0.5 V in maximally 1 ms is accepted.
    - The voltage convertion must stop when the battery voltage is 6.0 V and start automatically when the voltage is 6.2 V
3. have an efficiency of more than 90% on the conversion between battery voltage and the regulated voltages when the current is between 1 mA and 1 A
4. turn on and of the supply voltages for up to 8 subsystems when ordered to by CSP
    - Turned off means that the subsystem must not be able to use more than 1 nA of current when shorted
    - The maximally time to turn on and off a subsystem must maximally be 10 ms
5. Turn off all subsystems when the EPS is rebooted
6. Be able to measure each subsystem by a precision of 20% from 50 mA to 500 mA
7. Turn off a given subsystem autonomously before 1 s if the current or temperature of the subsystem exceeds a predefined level.
8. Be able to measure the battery voltage with a precision of 0.05 V

9. Be able to measure the charge and discharge current of the batteries with a precision of 10 mA
10. Be able to measure 10 temperatures in the platform and mechanical structure and one temperature pr subsystem with a precision of 2 °C in the interval -40 °C to +120 °C
11. Send a message to LOG through CSP when operations is effected or fails

A.2 LOG

The LOG subsystem must:

1. Archive log messages from all subsystems
2. Save log messages in four priorities.
3. Keep the content of the log tables even if the system is rebooted
4. Save all log messages with a timestamp of four bytes
5. Be able to store log of seven days when one log messages is stored every 2 seconds which equals to 203,400 log messages
6. Send all log data or parts of it when requested through CSP

A.3 FPF

The flight planner must:

1. Be able to save commands that is received through CSP about tasks that have to be executed at the time that is defined in the message
2. Be able to delete a task that is already created in the flight planner when commanded to by CSP
3. Must execute the received tasks within 1 s of the given time, where the time reference in the experiment is used as reference
4. The tasks must not be deleted if the FPL subsystem is rebooted or turned off
5. Contain a real time timer that maximally must differ 10 s per day
    - The timer must not be reset, even if the system is rebooted
6. Answer correctly at a time query from other subsystems
7. Contain 270 tasks, which each holds a time for executing, a subsystem ID and the command to execute
8. Send a message to LOG each time a task is executed
9. Be able to send all content of the flight plan over CSP when commanded to over CSP
10. Have all tasks stored redundantly and with checksum
11. Only execute tasks with a correct checksum. If a checksum fails is detected, the same procedure must be used for the other version of the task

A.4 UHF

1. The radio must interface to on-board sub-systems using CSP
2. The radio must bridge traffic from the on-board CAN network to the spacelink in a transparent matter depending on the destination address of the traffic
3. The sofware should be so general that the same system can be used for ground-station, or a redundant radio can be inserted
4. The radio should keep other subsystems aware of the state of the spacelink

A.5 ELA

1. The subsystem must interface to onboard subsystems using CSP
2. The subsystem must bridge traffic from the onboard CAN network to the E-link supplied by BEXUS in a transparent matter depending on the destination address of the CSP traffic

A.6 AIS1

A.6.1 Hardware requirements

1.1 Temperature
The temperature will be very low when the balloon ascends. The system needs to be fully functional at all time during the balloon flight. Which means that the receiver needs to be capable of working in temperature below -40 °C.

1.2 Vacuum
When the balloon reaches an altitude of approximately 35 km the air is very thin, almost like vacuum. So the system needs to be working in vacuum like conditions.

***1.3 Size**
All the PCB's is going to be mounted in the AAUSAT frame which size is 10*10*10 cm. The PCB's needs be able to fit in the AAUSAT frame.

1.4 Power usage
The experiment on the balloon will run on batteries and those batteries needs to fit in the AAUSAT along with the PCB's. This reduces the amount of power the experiment can use, which must be held to a minumum.

1.5 EMC
The system must comply with the general EMC directive DS/EN 61000-6-3:2007[Standard 09]. The balloon is equipped with several communications systems which the experiment is not allowed to interfere with. The limits is not specified in the Bexus balloon flight manual but an interferes test will be done right before flight. If the experiment fails this test, the experiment will be grounded. Furthermore the system must be able to withstand the high-power RF signals, transmitted from the balloon communications systems and comply with DS/EN 61000-6-3:2007 [Standard 09].

A.6.2 Functional requirements

2.1 AIS receiver must receive AIS messages
The system must be able to receive AIS data from the Norwegian cost to the North Atlantic Sea and the Gulf of Bothnia in the Baltic Sea when mounted on the Bexus balloon flying at an altitude of 35 km over Esrange in Sweden.

2.2 Store demodulated data
The system must be able to store continually received raw bits data on the Bexus balloon flight on a non-volatile memory.

2.3 Interface with CAN using CAN-Space-Protocol (CSP)
The system must interface with CAN and use the CSP protocol to enable communication with other devices.

2.4 Readout signal strength
The system must be able to measure and readout the Signal strength of the AIS signal.

2.5 Set the center frequency in the receiver
The environment the system will needs to be working in is very hostile and due to low temperature and weather conditions the center frequency can changes. The systems needs to be able of changes the center frequency so that it can be adapted to the conditions.

2.6 The system must be able to convert raw data to NMEA strings
The ground station will be equipped with a NMEA to map plotter which can convert a NMEA package into a dot on a map on a screen. So the systems needs to be able of creating NMEA packages which can be used on the ground station.

2.7 The system needs to sort in the received packages
The system must be able to read which type of message that is received, and be able to store a specific type of package. The system only needs to store the type of packages which contains the MMSI position.

2.8 The system needs to be suitable of uploading all the received data
The system must be able to sent the raw bit data collected and the stored NMEA packages using either the UHF radio or the E-link.

A.7 AIS2

1. be able to sample raw data which contains both AIS channels with a sufficient sample rate to satisfy the Nyquist sample theorem
2. must do the demodulating in software and must be able to update all parts of the demodulating and decoding software remotely
3. be able to demodulate and decode 90% of received AIS messages correctly when received effect is ?? mW and SNR is ?? dB
4. be able to compensate for frequency drift, including dobbler shift when the satellite is moving with 7.5 $^{km}/_{s}$
5. be able to store raw sampled data for 3600 sec (1 hr) and 1000 decoded packets
6. be functional from -40 - +85° C
7. have a weight of maximally 150 g
8. be operating for at least 6 months
9. comply with the standards defined by the AAUSAT3 system engineering group
    a) be able to run at 3.3 V and/or 5 V only
    b) use no more power than 1 W
    c) comply with the PCB layout for AAUSAT3 including definition of stack connector and board outline

d) have at least one temperature sensor placed on a central part of the PCB

e) be able to be controlled completely over CSP

f) send telemetry to the LOG subsystem

Appendix B

Introduction to AIS

This appendix will give a brief introduction to the functionality of Automatic Identification System (AIS).

B.1 System Objectives

AIS is an ITU standard designed to enhance safety at sea by automatic exchange of ship identification data. All ships with a gross weight of more than 300 tons and all ships carrying passengers is required by law to have an AIS transponder on board. For all other ships it is optional. AIS transponders continuously broadcasts info such as position, heading, speed, destination and name to other ships as well as shore based stations. The system is designed to function autonomously and allow ships to exchange information without influence of an operator. [ITU 07]

The AIS signal has several advantages compared to conventional radar systems. First of all, the AIS signal can be received even if the ship is hidden by landmass where a radar systems cannot detect vessels. AIS signal also contains information about more than just ship position, so the AIS receiver is often coupled directly to the radar of a ship, so all information can be found in one place.

As described, not all ships are required to have AIS equipment on board, this means the system can not give a complete picture of nearby ships. AIS is thus not intended to replace traditional radar or collision avoidance systems, but to function as an additional safety feature. It must be noticed that AIS defines several different packet types, so not all information is contained in a single packet.

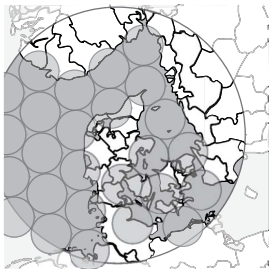
Besides ship-to-ship identification, AIS is used for monitoring ships by using shore based stations, strategically placed bouyes and electronic lighthouses.

B.2 High Altitude Challenges

AIS is build on using Time Division Multiple Access. At open sea it is not desirable to have special "master ships" that determine when other ships are allowed to broadcast in TDMA. In order to to avoid signal collisions when multiple ships broadcasts AIS messages, SOTDMA (Self-Organized TDMA) is therefore used.

This scheme raises some complications when attempting to receive AIS signals from space. As a satellite in Low Earth Orbit (LEO) can receive signals from a much larger area than ships at sea level, it is possible that the satellite will receive AIS packets from several TDMA zones. Message broadcast is only synchronized within each zone, so a satellite receiving traffic from different zones could lead to collision of packets being broadcasted by ships that are unaware of each others presence. It is necessary to apply probability theory to the signals, to estimate how many of the

signals will collide. Picture B.1(a) shows the footprint of a high altitude plane, and B.1(b) shows the footprint of a LEO satellite. In rarely sailed seas, a considerable part of the messages are expected to be received uncorrupted. More information about the footprints size from the Bexus ballon is to be found in apendix I.



(a) Illustration of how a planes AIS receive multiple TDMA zones in its field of view

(b) The circle illustrates how a LEO satellites field of view might be, compared to the dashed circle that illustrate a planes field of view

Figure B.1: Satellite and plane footprint of the Earth

B.3 The AIS Protocol

The different data types of information transmitted by AIS can be divided into two groups: Static Data and Dynamic Data. Figure B.3 lists the various types of messages that are transmitted in an AIS system.

Data	Type	Interval		
		Ship 0-14 knots	Ship 14-23 knots	Ship ¿ 23 knots
MMSI number	Static	6 min	6 min	6 min
Call sign & name	Static	6 min	6 min	6 min
IMO number	Static	6 min	6 min	6 min
Lenght and beam	Static	6 min	6 min	6 min
Type of ship	Static	6 min	6 min	6 min
Position (lat/long)	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Position accuracy	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Time stamp (UTC)	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Course and speed	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Heading	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Rate of turn	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec
Navigation status	Dynamic	3 min - 3,33 sec	2 - 6 sec	2 sec

Table B.1: Overview of AIS messages with travel information. The dynamic data transmitted is depending on how fast the ship is moveing. [ITU 07]

To give a short introduction to the basics of AIS and technical characteristics of the system, the AIS network protocol is reviewed based on the Open System Interconnection (OSI) model. Figure B.3 illustrates sublayers of AIS and their corresponding layer in the OSI model. The AIS standard covers the layers 1 to 4 (physical-, link-, network- and transport layer), which are described in the following sections

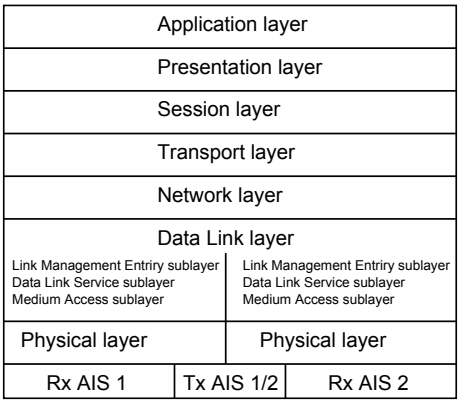


Figure B.2: Protocol stack of AIS

B.3.1 Layer 1: Physical Layer

In the OSI model the physical layer is the first and lowest layer. It comprises the basic hardware transmission technology of the network underlying the logical data structures of the higher level functions in a network. The physical layer is responsible for transmitting raw bits over the network and handling these over the Data Link Layer.

The AIS operates on the maritime VHF band on channels 87B and 88B (161.975 MHz and 162.025 MHz), with a bandwidth of 25 kHz. The bit rate of the AIS channels is 9600 $^{\text{bits}}/_{\text{s}}$.

The modulation scheme used is bandwidth adapted frequency modulated Gaussian minimum shift-keying (GMSK) due to the robustness of the scheme. During transmission, the GMSK modulator converts packets of network data into waveforms suitable for transmission over the channel. For receiving, it demodulates similar waveforms to data.

B.3.2 Layer 2: Data Link Layer

The data link layer provides the functionality to transfer data over the network. It provides the means to detect and the possibility to correct errors that may have occurred in the physical layer. In the OSI model the data link layer is divided into three sublayers, the Medium Access Control (MAC) layer, the Data Link Service (DLS) layer and the Link Management Entity (LME) layer.

Medium Access Control sublayer

The MAC sublayer provides a method for granting access to the data transfer media. To ensure a reliable and robust operation AIS builds on using Time Division Multiple Access (TDMA) scheme with a common time reference. The system is defined such that one frame equals one minute and is divided into 2250 slots with a length of 26,67 ms, where the slot length equals the length of a default transmission.

The synchronisation is achieved by using the global positioning system (GPS) co-ordinated universal time (UTC) as a reference for syncronication of the frames in AIS. This raises the probability of the frames in the different SOTDMA's starts at the same time. When the system is turned on it will listen for packets transmitted over the AIS channels and synchronises after these or as described listen for the UTC and use this to create a new SOTDMA cell. See figure B.3

Data Link Service sublayer

The DLS sublayer provides the methods for data link activation and release, data transfer and error detection and control. The data transfer uses a bit oriented protocol based on the high-level

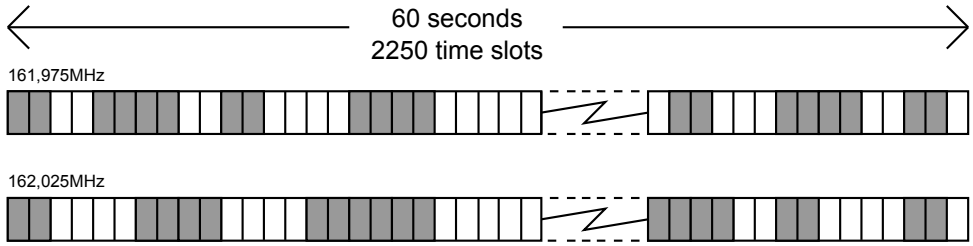


Figure B.3: AIS data divided into frames and slots

data link control (HDLC) protocol. For packet detection and synchronisation to work properly the data field of the packet is handled with bit stuffing.

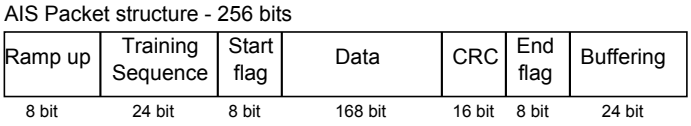


Figure B.4: AIS HDLC packet structure

Figure B.4 shows an 256 bits AIS packet, equal to one slot. The packet consists of the following fields:

- Ramp up (8 bits), is added so the transmission distance and synchronization errors does not affect the packet
- Training sequence (24 bits), alternating ones and zeros (01010101...) is used for synchronizing the packet
- Start flag (8 bits), the frame is (01111110)
- Data, payload (168 bits), 6-bit data field type. The data is bitstuffed
- CRC (16 bits), cyclic redundancy check
- End flag (8 bits), similar to the start flag
- Buffering (24 bits)

Link Management Entity sublayer

The LME sublayer controls the operations of DLS, MAC and the Physical Layer. The sublayer uses the TDMA information from the MAC sublayer to grant access to transmit data on the channel. Normally when powering on a AIS system, it will monitor the TDMA channel for one minute to determine the channel activity, current slot assignments and reported positions of other AIS users. The AIS transponder then enters the network and starts transmitting on the channel. If the system does not receive any AIS data in the first minute, it will start to transmit by using SOTDMA (Self Obtained TDMA) In this report this sublayer is not important, as the AIS subsystem developed is only intended to receive data.

B.3.3 Layer 3: Network Layer

The purpose of the network layer is to:

- Establish and maintain channel connections
- Manage and assign priorities to messages
- Distribute transmission packets between channels

The two frequency channels that are reserved for AIS use worldwide are AIS1 (161.975 MHz) and AIS2 (162.025 MHz). In normal mode of operation the system should simultaneously receive on both of these channels in parallel and to achieve this two TDMA receivers are required. The network layer is responsible for the reporting rate of the system, i.e. the time between AIS broadcasts. The reporting rate is influenced by speed and course changes of the ship.

B.3.4 Layer 4: Transport Layer

The transport layer acts as an interface to the presentation layer and is responsible for converting data, received from the presentation interface, into transmission packets of correct size.
[Munsin 02, pp. 26-27][ITU 07]

Appendix C

Interface Control Documents

PRELIMINARY VERSION - TO BE CONFIRMED!

Be aware that this is a preliminary version. Arguments and return values are very much a work in progress. The ICDs are primarily included to provide a functional overview of the subsystems.

C.1 EPS

Turn on subsystem	
Purpose:	Turns on a particular subsystem.
Command:	EPS_ICD_SS_ON(Subsystem nr)
Arguments:	Subsystem nr (EPS_SS_CAM, EPS_SS_ADCS, EPS_SS_AIS, EPS_SS_COM-S)
Response:	EPS_SS_ON_OK, EPS_SS_ON_FAIL
Comment:	

Turn off subsystem	
Purpose:	Turns off a particular subsystem.
Command:	EPS_ICD_SS_OFF(Subsystem nr)
Arguments:	Subsystem nr (EPS_SS_CAM, EPS_SS_ADCS, EPS_SS_AIS, EPS_SS_COM-S)
Response:	EPS_SS_OFF_OK, EPS_SS_OFF_FAIL
Comment:	

Ask whether subsystem is on	
Purpose:	Returns whether a particular subsystem is turned on. Returns EPS_SS_STATE_FAIL if the subsystem has been turned off due too high use of current.
Command:	EPS_ICD_SS_STATE(Subsystem nr)
Arguments:	Subsystem nr (EPS_SS_CAM EPS_SS_ADCS EPS_SS_AIS EPS_SS_COM-S)
Response:	EPS_SS_STATE_ON, EPS_SS_STATE_OFF, EPS_SS_STATE_FAIL
Comment:	

Measure temperature	
Purpose:	Get a measure of the temperature of a chosen sensor.
Command:	EPS_ICD_TEMP
Arguments:	Selected sensor
Response:	char temperature
Comment:	Answer will be delayed about 1 sec

Measure voltage	
Purpose:	To measure battery voltage or voltage on one the stabilized sources.
Command:	EPS_ICD_voltage
Arguments:	(EPS_Voltage_Battery EPS_Voltage_3V EPS_Voltage_5V)
Response:	char voltage
Comment:	There might will come more than one 3 V source

Measure subsystem-power-usage	
Purpose:	To measure current on a chosen subsystem.
Command:	EPS_ICD_PowerUsage_Messurement
Arguments:	(EPS_SS_CAM EPS_SS_ADCS EPS_SS_AIS EPS_SS_COM-S, _EPS_Power_Usage_Actual _EPS_Power_Usage_Mean _EPS_Power_Usage_Peak)
Response:	char current
Comment:	The peak and mean value is a 2 sec value

Activate power-usage peak and mean measurement	
Purpose:	To enable the satellite to make a peak and mean measurement.
Command:	EPS_ICD_PowerUsage_Activate
Arguments:	Subsystem nr. (EPS_SS_CAM EPS_SS_ADCS EPS_SS_AIS EPS_SS_COM-S) Measure type (EPS_Power_Usage_Mean EPS_Power_Usage_Peak)
Response:	_EPS_Power_Usage_Activate_OK, _EPS_Power_Usage_Activate_Fail
Comment:	

C.2 FPL

Enqueue new FP task

Purpose: To enqueue a new task to the FP, that the FP is to execute at the scheduled time
Command: uint8_t FP_FUNCTIONS_NEW(struct fp_task)
Arguments: struct{
uint16_t time;
uint8_t can0;
uint8_t can1;
uint8_t can2;
uint8_t can3;
uint8_t can4; }fp_task;
Response: FP_TASK_ENQUEUED, FP_TASK_NOT_ENQUEUED Comment:

Lookup FP task by id

Purpose: To lookup an already enqueued FP task by it's id, which is the execution time
Command: *fp_task FP_FUNCTIONS_LOOKUP_ID(uint16_t)
Arguments: uint_16, which is the id
Response: *fp_task, a pointer to the struct having the id from the arguent
Comment: Argument: execution-time = id
Returns a pointer to the requested struct

Lookup FP task by queue number

Purpose: To lookup an already enqueued FP by it's location in the FP, i.e. lookup the 1st FP to be executed
Command: *fp_task_lookup FP_FUNCTIONS_LOOKUP_NR(uint16_t)

Arguments: uint16_t being the FP's number in line - from 0 to 269
Response: *fp_task, a pointer to the struct having the position given in the argument
Comment:

Lookup all FP task

Purpose: To make a full FP download poissble
Command:
Arguments:
Response:
Comment:

Delete FP task by id

Purpose: To delete an already enqueued FP task by it's id, which is the execution time
Command:
Arguments:
Response:
Comment:

Delete FP task by queue number

Purpose: To delete an already enqueued FP task by it's location in the FP, i.e. delete the 1st FP to be executed
Command:
Arguments:
Response:
Comment:

Delete all FP tasks

Purpose: To reset the entire FP
Command:
Arguments:
Response:
Comment:

C.3 LOG

Save a logmessage

Purpose: A subsystem wants data to be logged.
Command: LOG_ICD_SAVE
Arguments: (uint8_t log identifier), (uint16_t data), (uint8_t priority (0-3))
Response: LOG_OK, LOG_FAIL
Comment:

Send latest logdata

Purpose: A subsystem/ground want to read the latest log-data. You must choose a number of log messages and a priority
Command: LOG_ICD_SEND_LATEST
Arguments: (uint8_t identifier), (uint8_t identifiermask), (uint8_t priority (0-3)), (uint16_t number of log messages)
Response: uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, ...
Comment:

Send logdata since time

Purpose: A subsystem/ground want to read the latest log-data. You must choose a number of log messages and a priority
Command: LOG_ICD_SEND_LATEST
Arguments: (uint8_t identifier), (uint8_t identifiermask), (uint8_t priority (0-3)), (uint16_t number of log messages), (uint32_t timestamp)
Response: uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, ...
Comment:

Number of logmessages since time

Purpose: Returns how much log has been saved since a given timestamp
Command: LOG_ICD_NUMBER
Arguments: (uint8_t identifier), (uint8_t identifiermask), (uint8_t priority (0-3)), (uint32_t timestamp)
Response: uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, uint8_t identifier, uint16_t data, ...
Comment:

C.4 UHF

TBD

C.5 ELA

TBD

C.6 AIS1

Get Current System State	
Purpose:	Get System State: Temperature, Menory Usage, Frequency etc.
Command:	AIS1_SYSSTATE
Arguments:	None
Response:	System State Data on success,
Comment:	Preliminary Version!

Change configuration of radio	
Purpose:	Change configuration of the ADF7021
Command:	AIS1_CONFIG
Arguments:	What config to change and to what
Response:	What configuration now is.
Comment:	Preliminary Version!

Tune frequency	
Purpose:	Tune the frequency of the VCO
Command:	AIS1_TUNE
Arguments:	UP or DOWN , stepsize
Response:	New Frequency
Comment:	Preliminary Version!

Number of received messages with correkt checksum	
Purpose:	Get number of received messages
Command:	AIS1_NUMMES
Arguments:	None
Response:	Number of received messages
Comment:	Preliminary Version!

RSSI of last received AIS-message	
Purpose:	Get RSSI of last received message
Command:	AIS1_RSSI
Arguments:	None
Response:	Value of RSSI
Comment:	Preliminary Version!

Get last received AIS-message	
Purpose:	Get last received AIS-message
Command:	AIS1_LMSG
Arguments:	None
Response:	last received AIS-message
Comment:	Preliminary Version!

Get AIS-message number	
Purpose:	Get a specifik AIS-message
Command:	AIS1_MSG
Arguments:	Message number
Response:	AIS-message
Comment:	Preliminary Version!

Get a string of AIS-messages	
Purpose:	Get a more than one AIS-message
Command:	AIS1_MSGSTRING
Arguments:	Message number start and messages number stop
Response:	AIS-message string
Comment:	Preliminary Version!

Turn OFF	
Purpose:	To prepare the AIS1 to be turned off
Command:	AIS1_OFF
Arguments:	None
Response:	Ready to be turned off
Comment:	Preliminary Version!

C.7 AIS2

The AIS2 subsystem has two main states: Manual Mode or Automatic Mode. This is illustrated in Figure C.7.

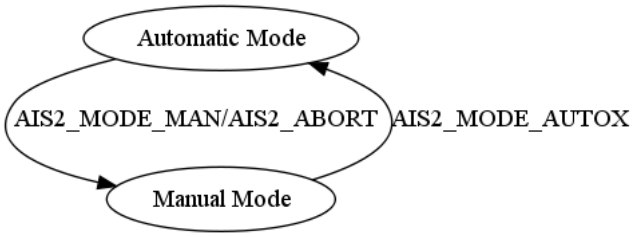


Figure C.1: AIS2 Main States

Abort Current Operation	
Purpose:	Abort the current operation and return to Manual Mode
Command:	AIS2_ABORT
Arguments:	None
Response:	AIS2_OK on success. If any issues arise, the system should still return to Manual Mode but return AIS2_WARNING
Comment:	Preliminary Version!

Get Current System State	
Purpose:	Get System State: Mode, Memory Usage, Temperature, etc.
Command:	AIS2_ABORT
Arguments:	None
Response:	System State Data on success, AIS2_FAIL on failure
Comment:	Preliminary Version!

Enable Automatic Mode	
Purpose:	Set the AIS2 subsystem in Automatic Mode
Command:	AIS2_MODE_AUTO(SUB_MODE)
Arguments:	SUB_MODE (AIS2_MODE_AUTO_SAMPLE AIS2_MODE_AUTO_PTRACK AIS2_MODE_AUTO_FREQEST AIS2_MODE_AUTO_DEMOD AIS2_MODE_AUTO_BITSYNC AIS2_MODE_AUTO_DECODE)
Response:	Selected mode on succes, AIS2_FAIL on failure
Comment:	Preliminary Version!

Enable Manual Mode	
Purpose:	Set the AIS2 subsystem in Manual Mode
Command:	AIS2_MODE_MANUAL
Arguments:	None
Response:	AIS2_OK on success, AIS2_FAIL on failure
Comment:	Preliminary Version!

Sample Data	
Purpose:	Sample Data
Command:	AIS2_SAMPLE
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Track Packets	
Purpose:	Track packets in the sampled data
Command:	AIS2_PTRACK
Arguments:	None
Response:	Number of packets found in data
Comment:	Preliminary Version! Low resolution FFT

Center Frequency Estimation	
Purpose:	Estimate the center frequency of packets in the sampled data
Command:	AIS2_FREQEST
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version! High resolution FFT

Demodulate Data	
Purpose:	Demodulate packets in the sampled data
Command:	AIS2_DEMOD
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Bit Synchronization	
Purpose:	Perform bit synchronization on the demodulated data
Command:	AIS2_BITSYNC
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Decode AIS packets	
Purpose:	Decode AIS packets in demodulated data
Command:	AIS2_BITSYNC
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Received Packets Stats	
Purpose:	Return stats on received packets: Number of packets, Passed/Failed CRC, Package type distribution
Command:	AIS2_RECEIVER_STATS
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

List Received Packets Headers	
Purpose:	List received packets headers
Command:	AIS2_LIST_PACKETS
Arguments:	None
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Get Specific Packet Content	
Purpose:	Get specific packet content
Command:	AIS2_GET_PACKET
Arguments:	Package number
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Set Algorithm Parameters	
Purpose:	Set Algorithm Parameter
Command:	AIS2_ALGORITHM_PARAM
Arguments:	Sample length, Store Failed CRC packets, Log settings, etc
Response:	AIS2_MODE_OK on success, AIS2_MODE_FAIL on failure
Comment:	Preliminary Version!

Software Upload	
Purpose:	Not applicable for BEXUS
Command:	-
Arguments:	-
Response:	-
Comment:	-

Run Test Case	
Purpose:	Run Test Case
Command:	AIS2_TEST
Arguments:	Test case number
Response:	AIS2_TEST_PASSED on success, AIS2_TEST_FAILED on failure
Comment:	Preliminary Version!

Power-On Self-Test (POST)	
Purpose:	Run Power-on Self Test
Command:	AIS2_POST
Arguments:	None
Response:	AIS2_TEST_PASSED on success, AIS2_TEST_FAILED on failure
Comment:	Preliminary Version!

Appendix D

Component List

The individual components are mentioned in chapter 3.

Appendix E

Circuits

Scematics for the Platform subsystem can be found in the file named `platform.pdf`.
Here the Power Distribution Unit (PDU) can be found in `pdu.pdf` and `switch.pdf`.

Schematics for the SAM7x system can be found in the files named `SAM7x_basic.pdf` and `SAM7x_io.pdf`.

Schematics for the AIS2 frontend is included in the file named `ais2_frontend.pdf`.

All PDF files are included at the end of this document.

Appendix F

Mechanical drawings

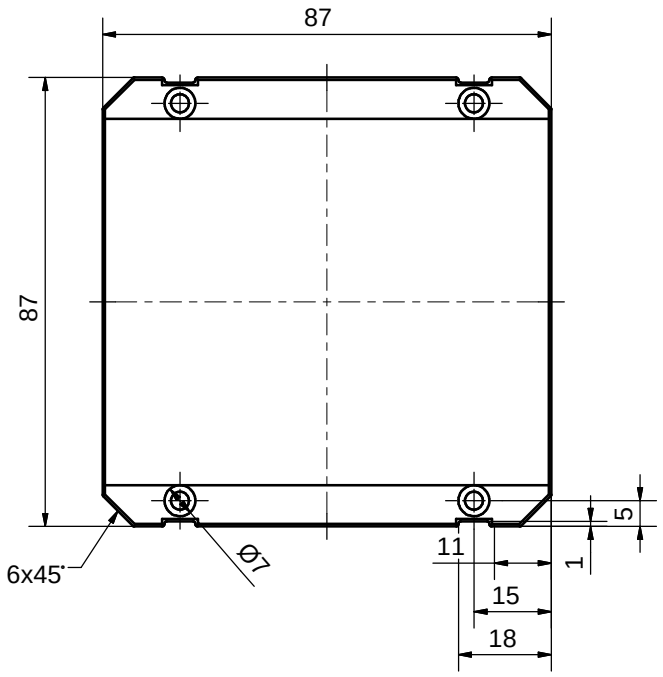


Figure F.1: PCB mechanical outline

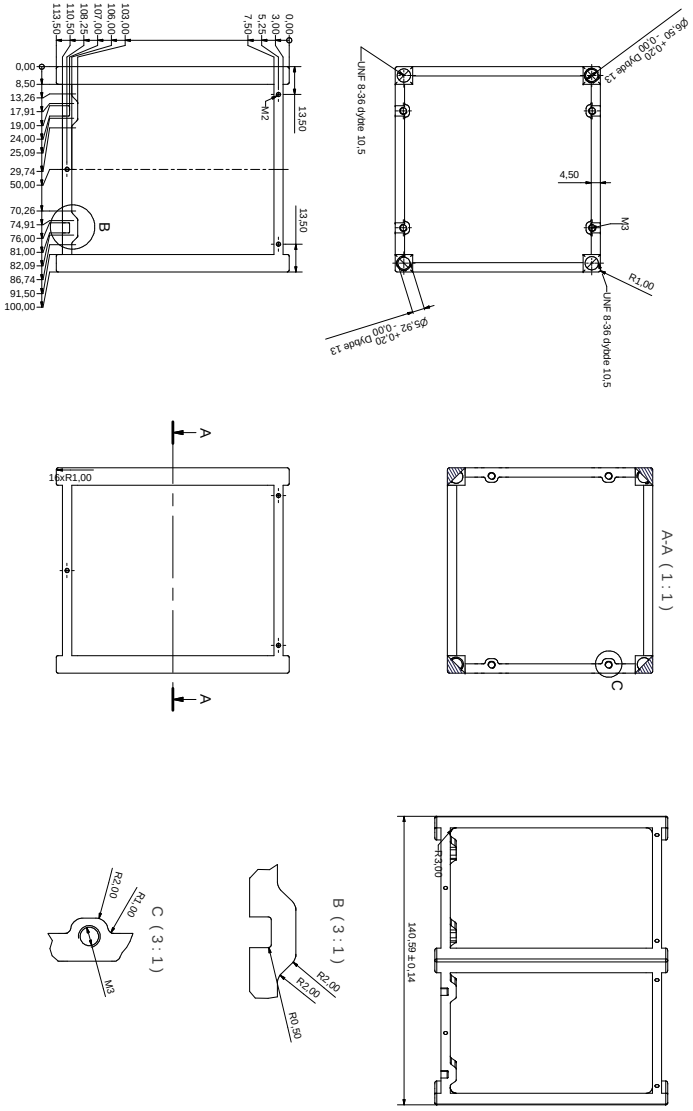


Figure F.2: Cubesat frame for mounting of PCB's

Appendix G

Pre-PDR experiments

In order to spot possible future problems, we have executed the following four preliminary tests.

G.1 Power Regulator Unit

The DC-DC converter, TPS62111, is planed to be used from our battery to supply the 3.3 V parts. Likewise, the TPS62112 is planed for 5 V supply.
TPS62111 has been tested for efficiency using a 8.4 V input supply.

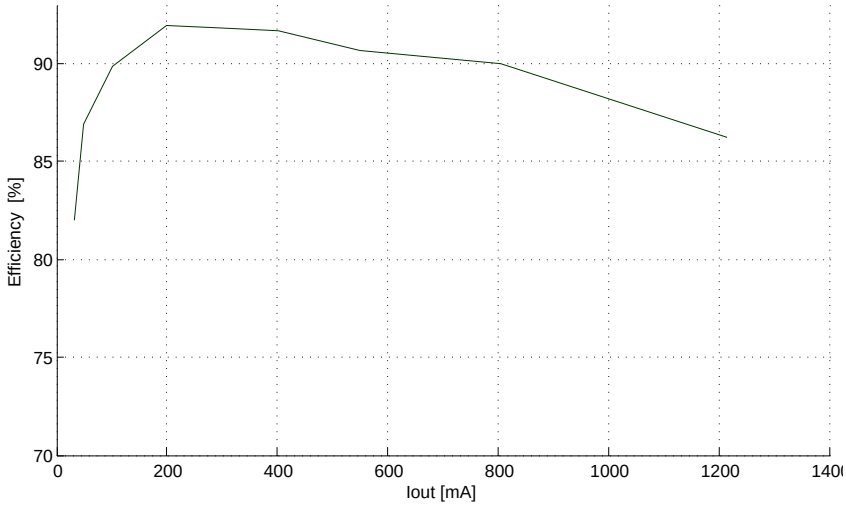


Figure G.1: 3.3 V DC-DC converrter test

G.2 Platform MCU

Using a previous developed PCB, the platform MCU (AT90CAN128) have been tested from -38 to 161 °C. The tested interfaces are parallel flash and CAN. The CAN interface have been tested using a standard PC and a USB-to-CAN adapter (PEAK USB CAN Dongle). At 161 °C the CAN communication fails.

G.3 Radio transceiver

The radio transceiver, ADF7021, are planed to be used, both in the AIS1 receiver and in the UHF up/down link. Also, the ADF7020-1 is planed to be used as a down converter for the AIS2 receiver.
Two ADF7021 was tested, using two AT90CAN128. One setup for transmitting and one for receiving. First, the transmitting setup was in the climate chamber, then the receiving setup.
The test was executed from -40 to 85 °C. The maximum transmitting frequency offset detected was 1 kHz, due to the internal temperature compensation. This test revealed some difficulties with the SPI interface of the AT90CAN128 when transmitting, no matter what temperature. This problem seems to be moisture related and requires more investigation.

G.4 AIS1 & ELA MCU

Both the AIS1 receiver and the ELA plan to use the AT91SAM7X MCU. Therefore, a development board, AT91SAM7X-EK, has been tested in climate chamber from -30 to 75 °C March 8th 2009. The test executed a freeRTOS demonstration code, counting network errors and packages. The only interface tested was ethernet, using a standard PC. No significant errors was detected, however a test of the other interfaces needed for the project must be executed.

Figure G.2: AT91SAM7X development board test

G.5 DSP development board

The OMAP3530 are planed to be used on the AIS2 receiver. A development board (aka. Beagleboard v. B6) was tested in climate chamber from -42.6 to 86 °C
The test included a linux distribution (Ångström), running from a 2 GB Kingston microSD card. The tested interfaces are: USB + USB hub, HDMI for display and SD card.

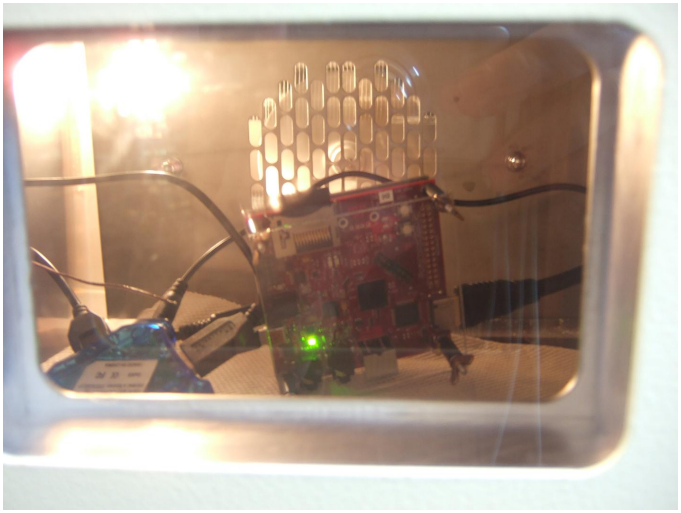


Figure G.3: OMAP development board test

Appendix H

Pre-CDR experiments

H.1 Isolation test

H.1.1 Vacuum

H.1.2 Isolation and heating

2 x 47R 4W resistor. 7.91 v * 0.345 A = 273W
Ambient: 22.5 Start: 22.5 t + 2: 35
Isolation power test:

Appendix I

Link budget

To make sure that it is possible to receive AIS messages in up to 35 km altitude, the received power is calculated at different altitudes. In this section, Friis transmission equation is used for calculations on the received power in the case of AIS reception and with a half-wavelength dipole as the transmitting and the receiving antenna. Assumptions have been made for simplifying the calculations. It is assumed that polarization mismatch is negligible, that impedance match is perfect and that weather has no influence on the signal attenuation. These assumptions are made on that the balloon only reaches 35 km in height and than the radio transmitted signal is normally reachable up to 75 km away [Pratt 03, pp. 317-326].
The ground effect (reflections) is not evaluated even though the ground effect may have a big impact on the received power in some regions. The worst case and best case scenario with ground effect is respectively when the signal is cancelled out and when the signal strength is doubled. The distribution of the to scenarios is considered random due to waves etc. and therefore considered not necessary for the link budget. The assumptions believe to be fair in order of calculating a good estimation on the received power. In order of using Friis's transmission equation, equation I.1.

$$\mathrm{P_r} = \left(\frac{\lambda}{4\pi \mathrm{R}}\right)^2 \mathrm{G_t Gr} |\hat{\rho} \cdot \hat{\rho}|^2 \mathrm{P_t} \tag{I.1}$$

Where $\mathrm{G_t}$ and $\mathrm{G_r}$ is the directive gain for the transmitting and receiving antennas respectively. The length from the ship to the balloon is R. The signal wavelength is λ. In the calculations it's assumed that polarisation mismatch has no influence, which means that $|\hat{\rho} \cdot \hat{\rho}| = 1$.
The directive gain for transmitting and receiving antennas, the length from the ship to the balloon and the signal wavelength, needs to be calculated. Each of these parameters will be calculated in the following. The calculations are done in Matlab.

Transmitter and receiver directive gain

It is assumed that ships are using half wavelength dipoles as transmitting antenna. In section 3.3 it was stated that a half wavelength dipole is used as receiving antenna on the balloon.
The electric field for at half wavelength dipole is given as. [Balanis 05, pp. 182]

$$E_\theta \approx j\eta \frac{I_0 e^{-jkr}}{2\pi r} \left(\frac{\cos\left(\frac{\pi}{2}\cos\left(\theta\right)\right)}{\sin\left(\theta\right)}\right) \left[\frac{\mathrm{V}}{\mathrm{m}}\right] \tag{I.2}$$

The constants j,η,I_0,k,r and θ in eqaution I.2 are respectively: The imaginary unit, free space impedance (intrinic)[120π], current [A], wavelenght [$\frac{2\pi}{\lambda}$], length of the antenna [m] and angle

[rad] The antennas are vertically polarized and are independent of the azimuth angle. The time-average power density and radiation intensity can be written respectively as. [Balanis 05, pp. 182]

$$W_{av} = \eta \frac{|I_0|^2}{8\pi^2 r^2} \left(\frac{\cos\left(\frac{\pi}{2}\cos\left(\theta\right)\right)}{\sin\left(\theta\right)} \right)^2 \left[\frac{\mathrm{W}}{\mathrm{m}^2} \right] \tag{I.3}$$

and

$$U = r^2 W_{av} = \eta \frac{|I_0|^2}{8\pi^2} \left(\frac{\cos\left(\frac{\pi}{2}\cos\left(\theta\right)\right)}{\sin\left(\theta\right)} \right)^2 \left[\frac{\mathrm{W}}{\mathrm{UnitSolidAngle}} \right] \tag{I.4}$$

The total radiated power can be calculated as.

$$P_{rad} = \int \int_s W_{av} \cdot ds = \eta \frac{|I_0|^2}{8\pi} \int_0^{\pi} \frac{\cos^2\left(\frac{\pi}{2}\cos\left(\theta\right)\right)}{\sin\left(\theta\right)} \ [\mathrm{W}] \tag{I.5}$$

The maximum directivity for a half wavelength dipole is:

$$D_0 = \frac{4\pi U_{max}}{P_{rad}} \ [-] \tag{I.6}$$

$$= \frac{4\pi U|_{\theta=\frac{\pi}{2}}}{P_{rad}} = \frac{4}{2.435} \approx 1.643 \tag{I.7}$$

The maximum directivity can replace $\eta \frac{|I_0|^2}{8\pi^2}$ in equation I.4. The term $\sin^3\left(\theta\right)$ can replace $\left(\frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} \right)^2$ in equation I.4. This replacing forms two new expression.

$$G_t = 1.643 \sin^3\left(\theta\right) \tag{I.8}$$

$$G_r = 1.643 \sin^3\left(\theta\right) \tag{I.9}$$

The maximum gain for a half wavelength dipole antenna is $10 \cdot \log(1.643) = 2.15\mathrm{dB}$ in $\theta = \frac{\pi}{2}$. Equation I.8 and equation I.9 are used for the transmitting and the receiving antenna.

Geometric analysis

The link budget is calculated using Friis transmission equation as described earlier. The angle from where maximum gain is obtained to the line of sight is to be calculated for the receiving and the transmitting antenna. This is important since neither the receiving nor the transmitting antenna has an isotopic radiation pattern. The following subsection is an explanation on how the two angles "Vship", "Vsat" and the length "R" is calculated. "Vship", "Vsat" and "R" are shown in figure I.1. The direct length from the balloon to the ship is called R (line of sight) and can be calculated with the following equation.

$$R = \sqrt{(b^2 + c^2) - (2 \cdot b \cdot c \cdot \cos(V))} \ [\mathrm{m}] \tag{I.10}$$

The angle between the directivity for the balloon antenna and R is obtained by focusing on the triangle formed by a, R and part of b.

$$Vsat = \arccos\left(\frac{\sin(V) \cdot c}{R} \right) \ [\mathrm{Rad}] \tag{I.11}$$

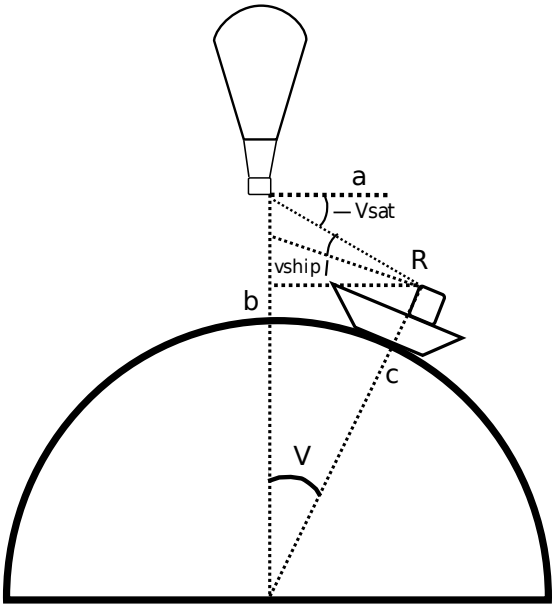


Figure I.1: *Angles and lengths used in the calculations*

The angle between the directivity for the ship and R can be expressed as.

$$Vship = \left(\left(\frac{\pi}{2}\right) - \left(\frac{\pi}{2} - Vsat\right) - V\right) \text{ [Rad]} \tag{I.12}$$

The two angles are used to calculate the gain of the ship and baloon antennas in the given direction. The length R is used in Friis transmission equation.

Calculating the link budget

The calculations for the link budget are done by sweeping the angle between the balloon and the ship starting from 0. The angle 0 is where the ship is located beneath the balloon. The sweep stops when the ships reaches the border for the FOV (field of view). The result of the simulation is illustrated in figure I.2. The calculations in figure I.2 is done by assuming earth's radius to be 6371 km constant. The transmitting antenna mounting height for the ship is set to 10 m. The frequency is set to 162,025 MHz (AIS ch. 2). The balloon altitude is set to 35 km. The radius of the footprint for the balloon can be calculated using the angles from figure I.13 and equation I.13.

$$\frac{2\pi \cdot earth's\ radius}{360^\circ} \cdot Angle\ in\ centre\ of\ earth \tag{I.13}$$

This can be used to calculate the signal strength as a function of the footprints radius. Strength as a function of the footprint size is illustrated in figure I.3. The graph in figure I.3 is plotted whit a map as background. Centre of the circles is ESRANGE (launch site for bexus balloon). Figure I.3 illustrates the signal strength. In the datasheet for the radio receiver a best case sensitivity is -113 dBm and it can thereby be concluded that it's possible to receive AIS massages even though launch site is fare from water.

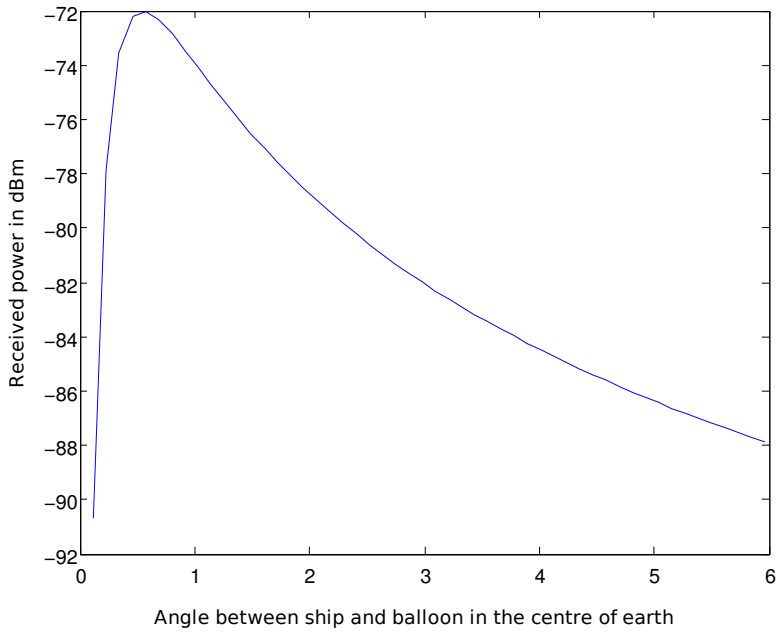


Figure I.2: *Received power measured in dBm as a function of the angle in the centre of earth measured in degrees*

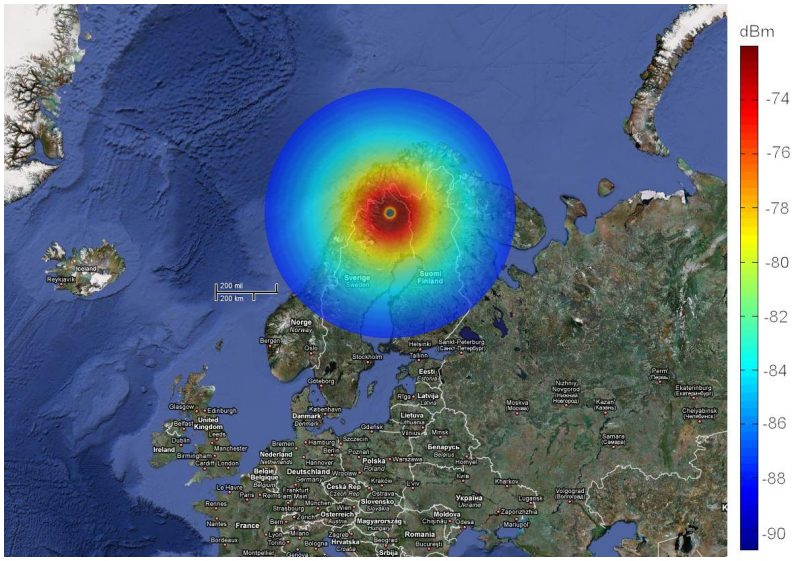


Figure I.3: *Received power measured in dBm as a function of the radius of the footprint*

Appendix J

PDR Comments

Organization and project planning

- Team seems to cover all competences and be well supported by CubeSat group and university.
- No test plan.
- Test facility only goes down to -25°C.

Mechanics

- Integration: add a plate to fix the experiment to the bottom of the gondola using rails. Another option would be to attach to the ceiling.
- Structure analysis (FEA and/or tests) is missing.
- Should withstand 10g vertical and 5g horizontal.
- Antenna: consider having a hanging antenna (for safety reasons).
- Assess the EMC and mechanical interferences with E-Link antenna.

Thermal

- The insulation of the experiment and batteries needs to be assessed not "assumed".
- Consider active thermal control

Electrical / Electronics

- Batteries: Same as used on AAUSAT2.
- Space qualified and rechargeable via external charger.
- Reliable (don't need BX batteries).
- Should assess the frequencies/power used.
- Swedish legislation.
- Local oscillators could disturb and/or be disturbed.

- Connectors: Use MIL-C connectors.
- Connections: Choice to be made between
- Either a cable coming out of the experiment going to BX (but long cable needed)
- Or a socket on experiment.
- E-Link: UTP protocol will be used by the team. Drivers and libraries already exist.
- Bandwidth needed/available on E-Link need to be assessed (also check requirements of other experiment teams).

Software

- Software is an major part of the experiment.
- Work started but need to give more details in the SED.

Risk assessment

- Assessment needs to include risks to the experiment but also to ground personnel and vehicle.

Operations

- Safety distances from antenna (prior and after flight) to be assessed.
- Team will have a full set of spare parts (mech and elec).

Outreach

- OK but need to make sure that there are specific actions about NAVIS-BEXUS and not only about AAUSAT3.
- Papers written need to be mentioned in the SED.

Summary of main actions for the experiment team

- Frequency assessment (ground station and broadcast).
- Proper analysis of boats in Baltic sea (consider footprint when balloon is drifting towards Finland).
- Mechanical integration on gondola.
- Test plan.

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